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THE CARE AND NURSING OF THE INSANE

P. J. BAILY, M.B.

PART I. ANATOMY AND PHYSIOLOGY

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CARE AND NURSING
OF
THE INSANE.

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Part I.

ANATOMY AND PHYSIOLOGY.

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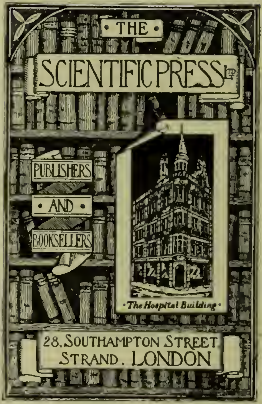

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PREFACE.

THIS little book is a reproduction of the course of lectures which for some years I have been giving to the staff of Hanwell Asylum. It is published in the hope that it may prove of some assistance to candidates for the nursing certificate of the Medico-Psychological Association of Great Britain and Ireland, and is intended rather to supplement than to replace the "Handbook for Attendants on the Insane."

My endeavour has been to describe the main facts of anatomy and physiology in such a manner that they may be understood by the uninitiated, a due regard being had for scientific accuracy, although this has occasionally been sacrificed for the sake of simplicity.

There is no claim whatever to any originality in the following pages, and I am naturally indebted to all the well-known authorities on the subject.

P. J. B.

Hanwell : January 1907.

THE CARE AND NURSING OF THE INSANE.

PART I.

ANATOMY AND PHYSIOLOGY.

1. THE TISSUES.

The materials of which the body is built are called *tissues*. These differ widely from each other in their nature and properties to suit the different uses to which they are put. One—called bone—is dense and hard; another—muscle—is capable of changing its shape by contraction; another—nervous tissue—has the power of originating thought and of conducting impulses or messages from one part of the body to another; still another—gristle or cartilage—is tough and elastic. All these tissues are of more or less solid consistence, but the blood which plays so important a part in the body is a fluid tissue. The various tissues are ensheathed and bound together to form organs by what is called ordinary connective tissue, while the organs themselves are associated in groups or systems. Thus the nervous tissues of the body form the brain, spinal cord, and nerves, and constitute the nervous system. The heart, blood-vessels and blood, and the lymphatic vessels, comprise the circulatory system. The tube through which the food passes from the mouth to the rectum, and certain glands connected with it, the digestive system. The air-passages and lungs, the respiratory system. The skin, the cutaneous system. The kidneys and their ducts and the bladder, the urinary system; and lastly the bones, cartilages, and ligaments, the skeletal system.

The Cells.

All the tissues of the body are built up of minute structures called cells, " comparable to the bricks of a house." These in their simplest form consist of little sacs or bladders of living matter (called protoplasm) surrounded by a delicate outer covering and containing a differentiated particle within them called the nucleus. Such simple cells are found in the outer covering of the skin, but in most of the tissues they are greatly modified in form and size so as to enable them to carry on the particular work which is assigned to them. With regard to the functions which these cells perform, they may be compared to the individuals in a community, each of whom has his own particular work to do for the common good.

The science of anatomy treats of the structure and arrangement of these organs and systems of organs, while that of physiology describes the manner in which they perform their work or functions.

Health.

So long as all the tissues and organs perform their functions so as to give the greatest possible amount of comfort to the individual, we say that a condition of health exists. This is the normal state, and the individual is not conscious of the existence of any of his organs. So soon as the functions of an organ are performed in such a manner as to give rise to discomfort or pain, in other words, when we

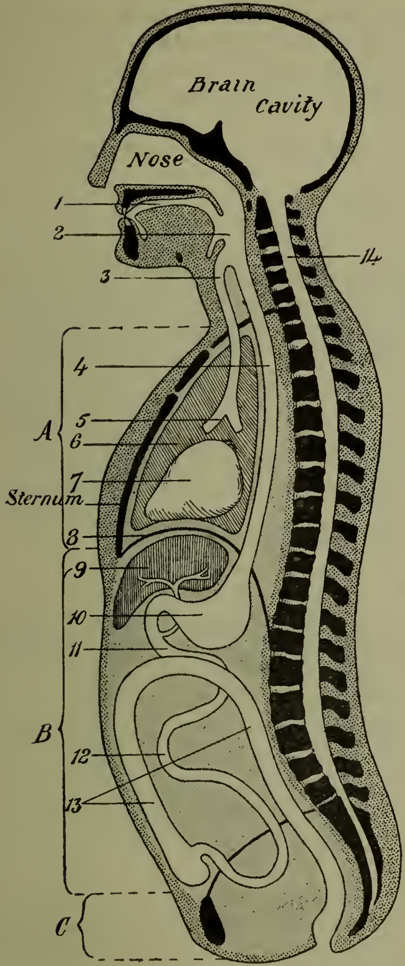

FIG. 1.—LONGITUDINAL SECTION OF THE BODY.

1. Mouth. 2. Pharynx. 3. Trachea. A. Thorax.—4. Œsophagus. 5. Bronchus. 6. Lung. 7. Heart. 8. Diaphragm. B. Abdomen.—9. Liver. 10. Stomach. 11. Duodenum. 12. Small Intestine. 13. Large Intestine. C. Pelvis. 14. Spinal Canal (for Spinal Cord).

become conscious of the existence of an organ—as when we suffer from toothache or palpitation of the heart—it indicates that the condition of health is departed from and that an abnormal state exists.

Primary Divisions of the Body.

It is obvious that the human body consists of head, trunk and limbs. If the body were divided into a right and left half by cutting it through the centre (fig. 1), it would be seen that the tissues are so arranged that certain cavities are formed, these cavities being boxes which contain what we may call the vital organs. They are two in number, one of them—the anterior (or front) cavity—is contained entirely within that portion of the body which we call the trunk. Its dimensions are comparatively large, and it is divided by a transverse muscular partition, called the diaphragm, into an upper part—the thorax or chest—and a lower part—the abdomen or belly.

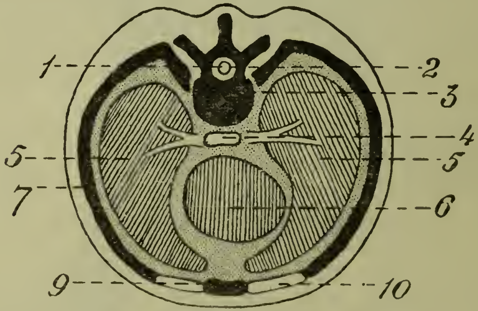

FIG. 2.—TRANSVERSE SECTION OF THORAX.

1. Spinal Cord. 2. Spinal Canal. 3. Spinal Column. 4. Gullet. 5. Lung. 6. Heart. 7. Rib. 9. Sternum. 10. Costal Cartilage.

The walls of the thorax are largely composed of bone (fig. 2), as we shall see, but those of the abdominal cavity (fig. 3) are almost entirely composed of muscles and fibrous bands. The lowest part, however, of the abdominal cavity is formed of a sort of basin whose walls are bony. This part of the abdomen is what is called the pelvis.

The chief contents of the thorax are the heart, lungs and gullet (œsophagus), together with many blood-vessels and nerves, and some lymphatic glands. These structures entirely fill the cavity.

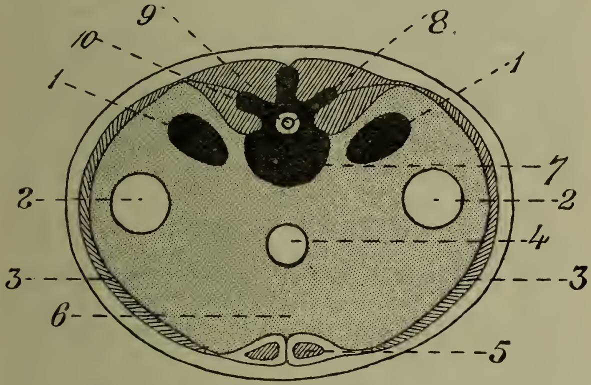

FIG. 3.—TRANSVERSE SECTION OF ABDOMEN.

1. Kidney. 2. Large Intestine. 3. Muscle. 4. Small Intestine. 5. Muscle. 6. Abdominal Cavity. 7. Spinal Column. 8. Spinal Cord. 9. Muscle. 10. Spinal Canal.

The abdominal cavity contains the stomach and intestines and the liver and pancreas, the kidneys and bladder, of which the latter lies entirely within the pelvis, and a large blood-gland called the spleen. There are also within the abdominal cavity many blood-vessels, nerves and lymphatic glands. In women the pelvis also contains the uterus, or womb, and the ovaries.

The second, or posterior, cavity of the body is throughout enclosed within bone. The upper portion of this is the cavity of the skull, which is directly continuous with a narrow canal which lies within the backbone and which is called the spinal canal. This second cavity, therefore, lies partly in the head and partly in the trunk. Its function is to contain and to protect the brain and spinal cord (the central nervous system) which lie within it.

The general shape of the body is maintained by the bones and cartilages which form the groundwork or frame or scaffold upon which the softer parts are arranged. As a rule the bones are covered with the muscles and these again are surrounded by a layer of fat, while the skin is a protective covering for all. In every tissue of the body (except cartilage) there are abundant blood-vessels and nerves.

2. THE SKELETON.

The popular notion of a bone is something which is dried up and uninteresting—"as dry as a bone," as we say. This idea, as applied to a bone in its living state, is very inaccurate. Each bone is an organ made up of many parts. It is abundantly supplied with blood-vessels and nerves, and is covered with a tough fibrous vascular membrane called the periosteum, by means of which the bone grows in thickness. The outer part of the bone consists of dense tissue, almost like ivory, but the interior is filled up with bony material of a much looser, almost spongy texture. Many bones, especially the long bones of the limbs, are hollow, the cavity being occupied with a substance called marrow. Those parts of a bone which in the formation of movable joints come into contact with other bones, are covered with a layer of cartilage; here there is no periosteum.

Bones

are composed of two quite different kinds of material (*a*) an earthy part, (*b*) an animal part.

If any bone be soaked for a sufficiently long time in a dilute mineral acid, the earthy part is dissolved out and the animal portion (which we may call gelatine) only remains. The shape of the bone is retained, but it is now soft and pliable and can be bent in any direction. If, on the other hand, a bone be subjected to prolonged boiling, the animal portion is dissolved, only the earthy part being then left. Here again the shape of the bone is maintained, but it is now very friable and can quite easily be broken with the fingers and reduced to powder. A normal bone may be compared to a well-starched linen collar, the stiffness is due to the starch which impregnates the linen, when this is washed out the linen becomes limp, just as a bone does when the earthy salts are removed by the acid.

Human bones offer all possible varieties of shape and size, but in this connection it is usual to classify them under four heads:—

1. Flat bones, of which examples are the shoulder-blade and breast-bone.
2. Long bones, such as the bones of the thigh and upper arm.
3. Irregular bones, like those which form the backbone.
4. Short bones, like those of the wrist and ankle.

We may consider that the functions of the skeleton are of a purely mechanical kind. It forms the groundwork upon which the body is built and around which the soft parts, muscles, etc., are arranged. By virtue of their hardness, the bones offer an effectual protection to the organs which they cover—such as the brain, spinal cord, heart, lungs, etc.—but one of their most important functions is to form levers, which are moved by the muscles attached to them, whereby motion and locomotion are produced.

The central portion of the skeleton is the backbone, or spinal column (fig. 4). This is made up of a series of irregularly shaped bones which are superimposed one upon the other. These are called vertebræ. Each vertebra consists of an anterior portion, or body, and a posterior portion or arch. These two parts are united together in such a way as to form a ring. It is these rings, placed one above the other, which form the spinal canal. There are, in all, thirty-three vertebræ, which are distributed as follows: seven in the neck (cervical), twelve in the back (thoracic or dorsal), five in the loins (lumbar). Below these there are two bones called the sacrum and the coccyx, of which the sacrum is formed by five vertebræ fused together, and the coccyx by four similarly fused together. During the earlier years of life these sacral and coccygeal vertebræ are all distinct from one another, but at about the eighteenth year fusion occurs and the five sacral vertebræ unite to form one bone—the sacrum; while the four coccygeal vertebræ unite to form the coccyx.

The sacrum is a thick and strong wedge-shaped bone, the broad end being directed upwards, and upon it the remaining portion of the spinal column rests.

The coccyx forms a small pointed bone (in man) which is curved forwards under the sacrum.

Each vertebra is separated from the one above and below it by a thick pad or cushion of cartilage or gristle, and all are bound together by strong fibrous bands or ligaments.

The sacrum is firmly fixed between the two haunch bones to which it is bound by ligaments. These three bones and the coccyx (the latter is quite unimportant) together form the skeleton of the pelvis.

The ribs, which are attached behind to the thoracic vertebræ, are arranged in pairs, of which there are twelve. Some of the ribs are connected in front with the breast-bone, not directly, but through the intervention of a piece of cartilage (fig. 5). Each rib is a long curved bone, and every one of the upper seven pairs is connected with the sternum or breast-bone by a separate piece of cartilage—the costal

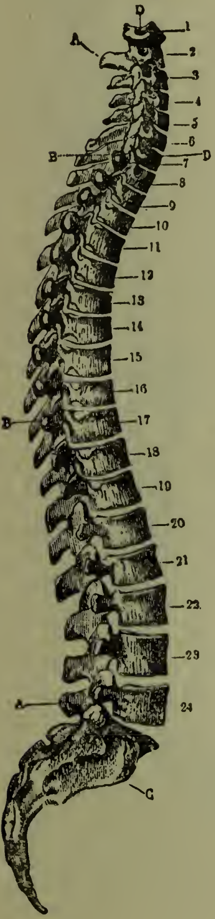

FIG. 4.—VERTEBRAL COLUMN—Lateral View.

1-7, Bodies of cervical vertebræ; 8-19, bodies of dorsal vertebræ; 20-24, bodies of lumbar vertebræ; AA, spinous processes; BB, articular surfaces of transverse processes for the tuberosities of the ribs; C, articular surface of sacrum.

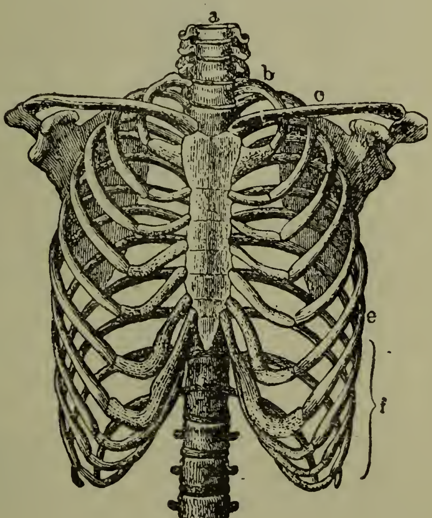

FIG. 5.—THE BONES OF THE THORAX.

c, clavicle; d, scapula; e, true ribs; f, false ribs; h, sternum.

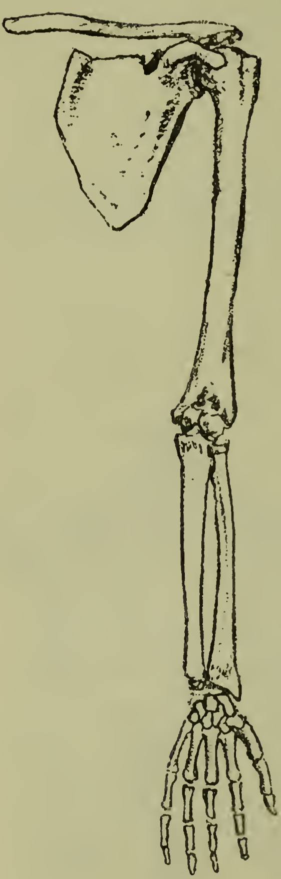

FIG. 6.

THE BONES OF THE UPPER EXTREMITY.

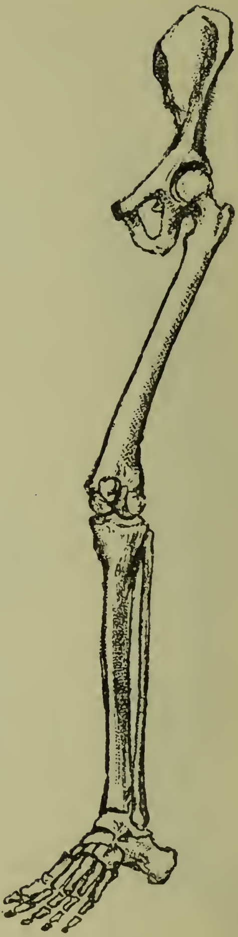

FIG. 7.

THE BONES OF THE LOWER EXTREMITY.

cartilage. These seven pairs are, therefore, called true ribs, and each pair with the cartilage and intervening sternum forms a sort of hoop round the contents of the chest or thorax. The remaining five ribs on each side are called false ribs, because they are none of them united to the sternum at all. The upper three on each side (the eighth, ninth, and tenth pairs) are connected through a common mass of cartilage with the cartilage of the lowest true ribs—the seventh pair. The lowest two pairs (the eleventh and twelfth) are quite free at their anterior ends and are hence called the floating ribs.

The breast-bone or sternum is a flattened piece of bone which forms the anterior or front portion of the thoracic wall. It is connected with the seven pairs of true ribs as has already been indicated.

The skeleton of the trunk is, therefore, made up of the backbone, the two haunch-bones, the ribs and costal cartilages, and the breast-bone.

The skull rests upon the upper end of the spinal column. It consists of a number of bones (22) which in adult life are all, with one exception (the lower jaw), firmly and immovably fixed to one another. The bones of the face form certain cavities or holes, such as the orbits which during life contain the eyeballs, the cavities of the nose and of the mouth, while those of the head form the cavity of the skull, or brain-box.

The upper limb is suspended from the trunk by means of the shoulder girdle (fig. 6). This consists of two bones on either side, the collar bone (clavicle), and the shoulder-blade (scapula). These two bones rest upon the upper part of the skeleton of the thorax and with their fellows of the opposite side may be compared to a milkman's yoke. Each clavicle is jointed at its inner or central end to the upper part of the breast-bone and at its outer end to the scapula. The clavicles hold the shoulders apart and the width of the shoulders, therefore, depends upon the length of the clavicles. The scapula is a flattish, three-cornered bone. At its upper and outer corner there is a shallow depression to which is jointed the head of the long armbone or humerus, forming the shoulder-joint. Below the lower end of the humerus are the two bones of the forearm which are called the radius and the ulna. These two bones form, with the lower end of the humerus, the elbow-joint. The radius is the bone on the outer or thumb side of the forearm, while that on the inner or little-finger side is the ulna. Of these two bones it is the upper end of the ulna which takes the larger share in the formation of the elbow-joint, but it is the lower end of the radius which takes the greater part in the formation of the wrist-joint, at which the bones of the forearm become associated with those of the wrist. In other words, it is chiefly the ulna which carries the forearm, whereas it is the radius which carries the hand. The bones of the wrist (carpal bones) are eight in number, they are bound together by ligaments and form a mass to which are attached the five bones of the palm (metacarpal bones). At their lower end these are jointed to the bones of the fingers and thumb; each finger has three bones, the thumb only two, which are called phalanges.

The bones of the lower limb correspond with those of the upper limb almost exactly in number and arrangement (fig. 7). On the outer side of each haunch-bone there is a deep cup-like hollow, into which fits the rounded ball-like head of the thigh-bone or femur. In the leg (that portion of the lower limb which is between the knee and the ankle) there are two bones which differ from one another very markedly, both in size and strength. The larger of the two, the tibia or shin-bone, lies on the inner or great-toe side of the leg. The other is a long slender bone, the lower end of which forms the outer prominence of the ankle. It is called the fibula, or brooch or splint bone. In the ankle there are seven small bones (the tarsal bones) most of them more or less cube-shaped, and the bones of the sole of the foot (metatarsal bones) and of the toe correspond exactly in number with those of the palm of the hand and fingers. There is one bone in the lower limb which is not represented as a separate bone in the upper limb. This is the knee-cap or patella. It lies in front of the knee-joint which it helps to protect from injury. It is tied to the upper part of the tibia by a strong fibrous band or ligament.

3. THE JOINTS.

A joint is formed by the contact of two or more bones. As a rule the object of a joint is to allow of motion. The amount of motion which may occur at any joint is very variable, and in some there is none. Hence joints are classified into three main classes:—(1) Those which are immovable; (2) those which are partly movable; (3) those which are freely movable.

1. Immovable joints are such as occur between the bones of the head and face. Frequently the edges of the bones which come into contact with one another are serrated or toothed, the teeth of one bone fitting tightly into the notches of the other. The two bones are separated from one another only by the periosteum, and are firmly tied together by ligaments.

2. Partially movable joints are found between the bodies of the vertebræ. The opposing surfaces of bone are separated from one another by a thick pad of cartilage, and are bound together by strong ligaments. The amount of movement which occurs at these joints is appreciable but very limited.

3. Movable joints are all constructed on the same plan. The surfaces of the bones which come into contact with one another (articular surfaces)

are covered with a layer of cartilage, and the joint is surrounded by a strong fibrous capsule which is thickened in parts to form bands or ligaments. These ligaments are (generally speaking) attached to the bones beyond and around the cartilage which covers their articular surfaces, and are sufficiently loose to allow of the requisite amount of motion. The inside of the joint is lined by a delicate membrane which, however, does not extend over the cartilage; it secretes a thick syrupy fluid which acts as a lubricant to the joint. The membrane is called the synovial membrane, and the fluid it secretes is the synovial fluid. It is this structure in the joints which becomes inflamed in rheumatic fever. The muscles which surround a joint help to strengthen it and to keep the bones in their proper places. Movable joints are found in a variety of forms, which allow of various kinds of motion. Of these the most important are: —

1. Gliding joints. In these the articular surfaces are nearly flat, and the only kind of motion possible is one in which one surface glides over the other. Such joints are found between the small bones of the wrist and foot.

2. Hinge joints in which the kind of movement resembles that of a hinge—that is to say, movement at these joints is only possible through one dimension in space. Examples of such joints are the knee and elbow.

3. Ball and socket joints in which the rounded ball-like end of one bone fits into a hollow cup in the other. In these joints movement occurs through all dimensions of space. The shoulder and hip-joints are examples.

Certain terms which are applied to the various kinds of movement which may take place at any joint require explanation. When a limb is bent upon itself, as when the hand is brought towards the shoulder by bending the elbow or when the foot is raised towards the buttock by bending the knee, the movement is known as flexion. The opposite movement, that of straightening the limb, is called extension. When a limb is carried away from the middle line of the body, as when the arm is carried out from the side or when, standing upon one foot, the other is carried out sideways, the movement is known as abduction. The opposite movement is adduction. The terms pronation (lying upon the face) and supination (lying upon the back) refer to the movement of the radius around the ulna. If, when sitting at a table, the hand is allowed to rest upon it with the palm upwards the hand is said to be in the supine position, the radius is then lying along the outer side of the ulna. When the hand is turned over so as to lie upon the palm it is said to be in the prone position, and the movement from the one position to the other is called pronation. During this movement the lower end of the radius rotates around the lower end of the ulna and carries the wrist and hand with it. In the position of pronation the radius lies more or less across the ulna. The change back again from the prone to the supine position is effected by the movement of supination. Circumduction is the name given to the movement which occurs when the arm is allowed to swing round and round at the shoulder joint, or when, standing upon the toes of one foot, the other foot is made to perform a circular movement from the hip-joint. "Rotation signifies movement of a bone round its axis without any great change of situation." If the arm is allowed to hang at the side of the body with the palm looking backwards, it can easily be turned completely round so that the palm looks forwards. Much of this movement occurs below the elbow-joint, and is one of supination, but if the arm be grasped by the opposite hand while the movement is being made the arm bone can be felt moving. This movement of the humerus is one of rotation at the shoulder-joint.

4. THE MUSCULAR SYSTEM.

The muscles are the agents of motion. The peculiar property of muscular tissue is its ability to alter its form. This power of contraction, as it is called, is brought into action at the bidding of the nervous system, as we shall see later. Every movement which is performed with or within our bodies depends upon muscular contractility.

There are two varieties of muscles. One variety is under the power of the will and acts only in response to the wishes of the individual. Hence this sort of muscles is spoken of as voluntary muscles. The other variety, although equally controlled by the nervous system, acts entirely independently of the will, and these muscles are therefore called involuntary muscles.

(1) *The Voluntary Muscles.*—These compose the greater portion of the bulk or flesh of the body and constitute the lean part of a joint of meat. As an organ, a voluntary muscle consists of more than mere muscular tissue. It is composed of many bundles of muscle fibres which are enclosed within the meshes of a network of fibrous tissue in which run many blood-vessels and nerves. These meshes or partitions are continuous with a fibrous covering or sheath, which surrounds the whole structure. At one end (sometimes both) this fibrous tissue is generally prolonged beyond the muscle-tissue and forms a strong cord-like band called the tendon or leader. The fleshy portion of the muscle is called the belly. Most of the voluntary muscles are attached by both their ends to different bones, consequently, when the muscle shortens or contracts, the bones are moved. The tendon is usually attached to the bone which undergoes the greater motion (the insertion of the muscle). The attachment of

the fleshy end or belly of the muscle (which occupies a much greater surface of bone than the insertion) is to the more fixed bone (the origin of the muscle). A few of the voluntary muscles—those of expression—are attached to the skin of the face and by their action alter the appearance of the features in response to various emotional states.

(2) *The Involuntary Muscles.*—These are found in the heart, in the walls of the blood-vessels, in the walls of the stomach and intestines and of the bladder, etc. They have no tendons and exist generally as thin layers of muscular tissue (except in the heart, where they occur in considerable bulk). They cannot be affected by the will although they are controlled by the nervous system and are easily influenced by certain emotional conditions, as is seen in the act of blushing. They are concerned in such vital actions as the circulation of the blood, digestion, etc.

5. THE CIRCULATORY SYSTEM.

Under this heading we must consider: (1) The blood, which is a fluid tissue; (2) the heart; (3) the blood-vessels; (4) the lymph; (5) the lymphatic vessels and glands.

We have seen that our bodies are built up of an innumerable number of minute tissue elements called cells and that these cells may be regarded as having the same relation to the whole body as do individuals to a nation or community. Now, we as individuals have many wants, we must be supplied with the necessities of life—our bread and our tea and our sugar—we must be able to procure clothes, and when these are worn out we treat them as waste and get rid of them. In like manner the cells of our bodies must be supplied with the necessities of life, and the waste which is the result of the wear and tear of life must be carried away from them, even as our old clothes are borne off by the old clo' man. As we shall presently see, it is the blood which is the agent by whose means these necessities are carried to the cells and the waste borne away from them. We know from common experience that whenever we get a wound in any portion of the body, however small the wound may be, whether only a scratch or graze or the prick of a needle, the blood escapes. After the bleeding has stopped there still exudes from the wounded surface until healing is complete, a more or less watery fluid which in small wounds such as a graze, ultimately dries up and forms a scab. This latter fluid we may call (for our present purposes) lymph.

We must now learn something about the blood, what it is composed of and by what mechanical arrangements it is carried to the various parts of the body; what is the nature of the work it performs, and what are its relations to the various tissue elements.

The Blood.

When we look at blood which has just been shed, without the aid of a microscope, we seem to be dealing with a simple red fluid. But if the blood be allowed to stand for a short time (two or three minutes) and then again examined, we find that it has undergone a very remarkable change; it is no longer fluid, it has, in fact, become transformed into a soft jelly—in other words, it has clotted or coagulated. If this clotted blood be allowed to remain for some time and then again examined, the clot will be found to have shrunk and to have become rather firmer, while at the same time an almost colourless (really pale straw coloured) fluid has been squeezed out of it.

Now let us put a drop of newly shed blood beneath a microscope and examine it. Our ideas about it will once more be changed. We find that it consists of two parts—namely, a fluid part which is almost colourless and a solid part consisting of numerous minute particles. The fluid part of the blood is called the blood plasma, while the particles which float in it are the blood corpuscles. After two or three minutes if we look through the microscope more carefully we shall be able to distinguish a number of minute hair-like filaments which form a network within whose meshes the corpuscles are entangled. These filaments are composed of fibrin, and the clotting or coagulation of the blood is due to its presence. So long as the blood is contained within the living and healthy blood-vessels this fibrin remains dissolved in the blood plasma and the blood remains fluid.

The corpuscles are of two kinds. The coloured or red, and the colourless or white (fig. 8).

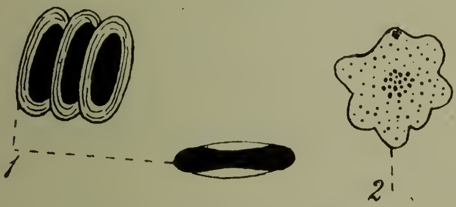

FIG. 8.—BLOOD CORPUSCLES.

1. Red. 2. White.

1. The red corpuscles are the more numerous (400 to 1). They are flattened circular discs like little biscuits, and are very soft and elastic. They are composed of a substance called protoplasm, which may be compared to the white of an egg, surrounded by a very delicate membrane or covering. They are so small that they can easily pass through the most minute vessels in the body, it would take about 3,200 of them set in a row with their margins touching to measure a line one inch long. In other

words they are about $\frac{1}{3200}$th of an inch wide. When seen singly as with a microscope they appear to be of a pale yellow colour, but when massed together they give the blood its red colour. It is quite impossible to convey by words any correct impression of their vast numbers in the blood, but we may say that roughly speaking in one single drop of blood they are about as numerous as the whole of the inhabitants of the globe. Each of these corpuscles is really a modified cell. Their colour is due to the presence in them of a very complex chemical substance called hæmoglobin. Iron is one of the constituents of this body. This explains the reason why iron is prescribed in certain cases of anæmia; anæmia being a condition in which the hæmoglobin of the blood becomes deficient in quantity.

The function of these red corpuscles is to carry oxygen from the air to the tissues, as we shall see more particularly presently.

2. The white corpuscles are less definite in shape than the red and moreover their form varies from time to time. They are rather larger than the red corpuscles and are like them composed of protoplasm. They may be taken as typical examples of the simple cell. We need not here concern ourselves with their function.

The plasma of the blood is, as we have seen, an almost colourless fluid. It has a saltish taste. It is slightly "sticky." It holds various substances in solution including the foods which it gathers after these have been digested, from the stomach and intestines. It also contains various waste matters which are thrown into it as a result of the wear and tear of the tissues. In addition to these it contains the fibrin which, as we have seen, is the cause of the coagulation of the blood after it has been shed.

The power of coagulation which the blood possesses is the chief agent in bringing about the natural arrest of hæmorrhage.

The Heart and Blood Vessels.

In no part of our bodies does the blood come into actual contact with the tissue elements or cells,* but it is contained entirely within a system of closed tubes which are collectively spoken of as the blood-vessels. These blood-vessels are found in every tissue in the body (except cartilage) and through them the blood is forced by the pumping action of the heart. The simplest form of heart—that of the cockroach for example—may be aptly compared to a Higginson's syringe. It consists of a simple tubular dilatation with muscular walls, so that when these walls contract the blood which is contained within it is forced out, just as the contents of the bulb of a Higginson's syringe are forced out by the pressure of the hand. Each end of the bulb of the syringe is provided with a valve and these valves allow the water to move only in one direction through the syringe.

The human heart (fig. 9) is necessarily a more complicated structure than this simple one of the cockroach, but it is arranged on quite the same principles—that is to say it is like the Higginson's syringe, a force pump, but instead of having only one chamber it has, as we shall presently see, four.

It is a hollow conical or pear-shaped muscular organ and lies within the thorax behind the breast-bone, resting upon the upper surface of the diaphragm. The greater portion of the heart is behind the breast-bone, but the point or apex of the cone projects beyond the left edge of the sternum and can be felt beating between the fifth and sixth ribs below the left breast. The thick end of the cone—the base of the heart as it is called—is the highest part as it lies in the chest and it is at this part that the great blood-vessels enter and leave the heart. It must not, however, be supposed that the heart rests upon its apex, it really lies upon its right side so that the apex points downwards and to the left, while the base is directed upwards and to the right, nor does it entirely depend upon the diaphragm for support since the great vessels which enter or leave it at the base, help to suspend it. In size it is generally said to resemble that of the closed fist of the person to whom it belongs and its weight is about nine ounces.

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* This statement is not strictly correct, since in the spleen and in the walls of the blood-vessels this does occur.

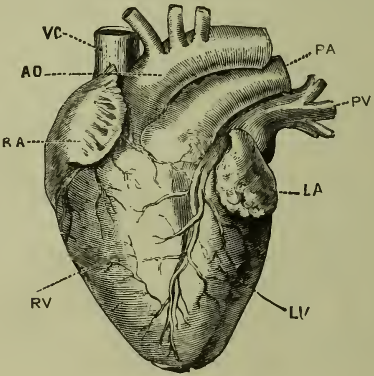

FIG. 9.—THE HUMAN HEART.

RA, right auricle; *RV*, right ventricle; *LA*, left auricle; *LV*, left ventricle; *AO*, aorta; *PA*, pulmonary artery; *VC*, vena cava superior; *PV*, pulmonary veins.

It is enclosed within a loose fibrous bag which is called the pericardium. This is attached around the base of the heart at the origin of the great blood-vessels, so that the apex of the heart lies quite free within it. The inner surface of the pericardium and the surface of the heart are smooth and glistening, and are separated from each other only by a very thin layer of fluid—the pericardial fluid.

The object of this arrangement is that the heart, which, of course, moves every time it contracts, may not be impeded in its action by rubbing against the surrounding organs. Throughout the body a similar arrangement is found wherever one part moves over another.

The interior of the heart is divided by a complete partition, which runs from the base towards the apex, into a right and left chamber. These two chambers have no communication with one another, so that the blood which is contained within one

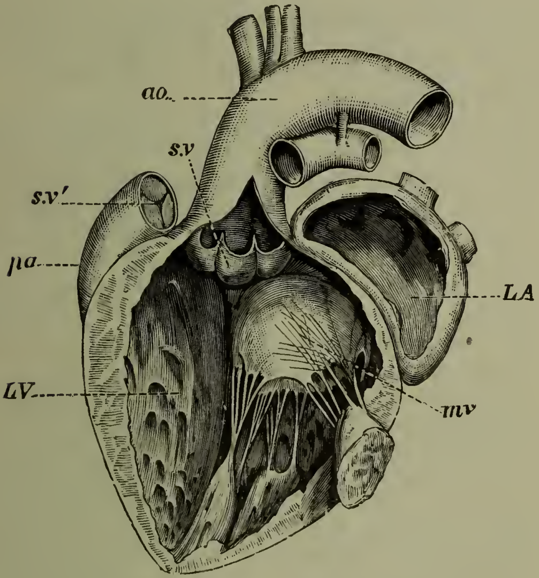

FIG. 10.—THE INTERIOR OF THE LEFT AURICLE AND LEFT VENTRICLE.

LA, left auricle; *LV*, left ventricle; *ao*, aorta; *pa*, pulmonary artery; *mv*, mitral valve; *sv*, semiluna valves of aorta; *sv′*, the same of pulmonary artery.

chamber is entirely separated from that which is contained within the other chamber.

Each of these two chambers is again divided into an upper and a lower part by a partition, which is, however, not complete, as there is an opening through which the blood passes from the upper chamber into the lower one on each side. Thus we see that the interior of the heart is divided up into four chambers, an upper and a lower one on each side, and that while there is no direct communication between the right and the left chambers, there is such communication between the upper and lower chamber on each side.

The interior of these chambers is lined by a membrane (the endocardium), which forms curtain-like folds around the openings between the upper and the lower one on each side (fig. 10). Of these curtains or folds (cusps) there are two on the left side and three on the right, and they hang down into the lower chamber. They are loosely tied down to the muscular walls of the lower chamber by fine but tough thread-like cords which are attached to their lower margins.

The upper chambers on each side are called the auricles, right and left, while the lower ones are the ventricles, also right and left; and the membranous curtains which hang down around the openings leading from the auricles into the ventricles are called valves. That on the left side with only two curtains is called the mitral valve, while the one on the right side with three curtains is called the tricuspid valve.

As we shall see presently, the left side of the heart has harder work to do than the right side, and therefore the walls of the left side are thicker than those of the right side. For the same reason the walls of the ventricles are thicker than those of the auricles. In association with this we may note the fact that valvular disease of the heart is more common on the left side than on the right side.

In addition to the openings which we have already considered, those, namely, which lead from the auricles into the ventricles, there are others in the walls of these chambers at the origin or termination of blood-vessels which either bring blood to the heart or carry it away from it (fig. 11). In each ventricle there is one such opening surrounded by three pouch-like membranous valves. Each of these valves is like a little bulging waistcoat pocket, the opening of the pocket looking away from the ventricle into the interior of the blood-vessel. Each

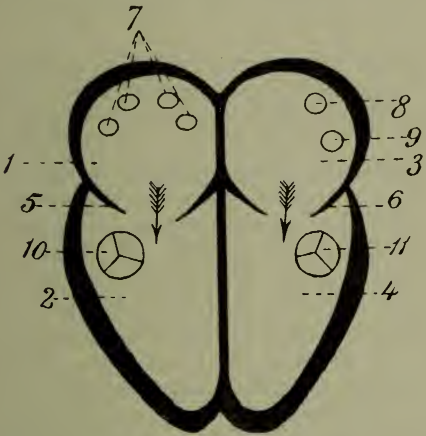

FIG. 11.—DIAGRAM OF THE INTERIOR OF HEART.
(Seen from behind).

1. Left Auricle. 2. Left Ventricle.
3. Right Auricle. 4. Right Ventricle.
5. One of the Cusps of the Mitral Valve.
6. One of the Cusps of the Tricuspid Valve.
7. The Openings of the Four Pulmonary Veins.
8. The Opening of the Superior Vena Cava.
9. The Opening of the Inferior Vena Cava.
These openings have no valves.
10. The Origin of the Aorta.
11. The Origin of the Pulmonary Artery.
Each of these openings is guarded by three pouch-like valves.

The arrows show the direction in which the blood flows.

pouch is quite close to its neighbour on either side, so that the three form a complete ring round the opening of the vessel which they guard, preventing the return of blood to the ventricle.

The openings in the walls of the auricles differ in number on the two sides; in the left auricle there are four, whereas in the right auricle there are but two. These openings are not provided with any valves.

The blood-vessels are a system of tubes which convey the blood from the heart towards the tissues and from these again back to the heart. Those which carry blood from the heart are called arteries, and those which bring blood back again to the heart are the veins. Between the arteries and veins there is a dense network of minute thin-walled tubes which surround the tissue elements and which are called capillaries. The arteries are continually giving off branches and therefore become smaller and smaller and more numerous the further they are from the heart. They continue to diminish in size until they merge into the capillaries, which are so minute that they require a powerful microscope to see them. Even the prick of a needle is sufficient to wound several of them. The capillaries then gradually unite with one another and so merge by degrees into the minute veins, and these again by uniting with others form the larger veins. Every portion of the body, every muscle, every bone, has its arteries, capillaries, and veins, and even the walls of the blood-vessels themselves are supplied with these vessels.

Now these blood-vessels of ours are not rigid tubes. The walls of the arteries and veins are composed chiefly of involuntary muscular tissue and what is called elastic tissue; they are consequently elastic tubes, that is to say, if pulled upon they stretch in the direction of the pull and when the pull is relaxed they return to their original shape. The larger arteries have a greater proportion of elastic than muscular tissue in their walls, but the smaller ones, those which immediately precede the capillaries, are almost entirely muscular. By the contraction or relaxation of the muscular fibres the size (diameter) of the vessels is altered, thus allowing a greater or less amount of blood to pass through it as occasion may require.

The structure of the walls of the arteries and veins is almost the same, only those of the veins are very much thinner than those of the arteries. The veins are both less elastic and less muscular than the arteries.

Many veins, especially those of the lower limbs, are provided with valves. These are little pouch-like folds of membrane exactly like those little pockets which surround the origin of the artery which comes off from each ventricle. In the veins, however, the mouth of the pouch looks towards the heart, away from the capillaries. We shall presently see what are the uses of these valves, which form an important difference in the structure of the arteries and veins. In the former vessels they are found only at the point of origin in the heart, whereas in the veins they are found at quite frequent intervals, at all events, in those of the lower limbs.*

Both the arteries and the veins, as well as the cavities of the heart, are lined with a delicate, smooth, very thin, glistening membrane. The walls of the capillaries are composed only of this membrane and they have neither muscular nor elastic tissue, but even they are stretchable so as to allow of a varying quantity of blood to pass through them.

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* These valves are not found in the pulmonary veins, the cerebral veins, nor the portal vein.

The Circulation of the Blood.

The circulation of the blood is the function of the whole circulatory apparatus. We must, therefore, now inquire into the various uses of these different component parts which we have been studying. It will be convenient, at the same time, to describe the remaining portions of the vascular system—namely, the lymph and the lympathic vessels and glands.

The Functions of the Blood.—We have seen already that the blood is the medium through which the wants of the tissues are brought to them and the refuse matters which they no longer require are borne away from them. We may, in fact, say that the blood is the general carrier of the body. The circulatory system is like a railway system whose trains are continually travelling, taking up and setting down produce or passengers at every station. In like manner the blood is continually travelling through the blood-vessels, giving as it passes something to the tissues, and in return receiving something from them; and since this is the case, it follows that certain changes must occur in the composition of the blood during its passage through the blood-vessels. Now it is in the capillaries that the business of the blood is transacted and that these changes in its composition take place, and the function of the arteries may be said to be merely to convey the blood to the capillaries, while that of the veins is conversely to convey it back from them to the heart, the latter organ being the motive force which by its contractions sets the blood in motion, forcing it through the arteries to the capillaries, and from these through the veins back again to itself. As we shall see presently, when we come to trace the course which the blood follows, there are in our bodies two sets of capillaries; one set we will call the pulmonary capillaries—these are in the lungs—the other set are the general or systemic capillaries, which, as we already know, form a dense network of minute tubes in every tissue and organ of the body (except cartilage).

The changes which the blood undergoes in its passage through the systemic capillaries are different from those which occur during its passage through the pulmonary capillaries. The blood which is carried by the arteries to the systemic capillaries contains a relatively large amount of oxygen gas, and is also loaded with the nourishment which has been poured into the blood-stream from the walls of the stomach and intestines. Both of these (oxygen gas and nourishment or food) it largely (not entirely) loses during its passage through the systemic capillaries, and in exchange for these it gathers up from the tissues carbonic acid gas and various other waste matters or refuse. At the same time (that is, during its passage through the systemic capillaries) it undergoes a remarkable change in its appearance. The pure blood, which is contained in the systemic arteries, is of a bright red colour—arterial blood, as we may call it—but while passing through the systemic capillaries it loses this bright colour and becomes a dull purplish or even quite purple colour; it is then called venous blood. This change in its appearance is due to the diminished amount of oxygen which it contains. The artery which carries the blood from the heart to the lungs (pulmonary artery) is loaded with this venous blood, which during its passage through the pulmonary capillaries again assumes a bright red colour, the reason for this second change in its appearance being that while in these (pulmonary) capillaries the blood takes in oxygen from the air and gets rid of carbonic acid gas.*

Thus we see that the blood carries oxygen from the lungs and nutriment (food) from the alimentary canal (stomach and intestines) to the tissues, while from them it carries carbonic acid to the lungs and other waste matters to the kidneys and skin. It is, in fact, always (while in the capillaries) losing something and always gaining something.

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* The "respiratory function of the blood" will be better understood after reading the section which deals with respiration.

Its sources of gain are:—(1) The alimentary canal (nourishment); (2) the lungs (oxygen); (3) the tissues (various waste matters and heat).

Its sources of loss are:—(1) The lungs (carbonic acid, water, and heat); (2) the tissues (nourishment); (3) the kidneys and skin (various waste matters, water, and heat).

During the whole period of life there is an incessant stream of blood flowing from the heart through the arteries to the capillaries, and from these through the veins back to the heart. This stream of blood naturally differs in quality in different parts of the circulatory system. Thus the blood passing into the lungs through the pulmonary artery contains the largest amount of carbonic acid and the smallest amount of oxygen. It also contains much food material taken up by the veins of the alimentary canal, and it is devoid of much waste material which has been removed from the blood by the kidneys and skin. The blood returning from the lungs differs from that going to them merely by being richer in oxygen and poorer in carbonic acid.

But not only does the blood vary in quality in different parts of the body; it also varies in temperature. The hottest blood is that which comes from the muscles, especially when these are in action, and from some of the internal organs; while the coolest is that which returns from the lungs and the skin. By the mixture of this warmer and cooler blood the temperature of the body is regulated and distributed.

Briefly, the functions of the blood are as follows:—

1. The respiratory function, by which is meant the carrying of oxygen from the lungs to the tissues and of carbonic acid from the tissues to the lungs.
2. The nutritive function.—The carrying of nutriment from the alimentary canal to the tissues.
3. The cleansing function.—The carrying away of various waste matters (other than carbonic acid) and water from the tissues chiefly to the kidneys and skin.
4. The regulation and distribution of heat.

The changes which the blood undergoes in the various capillaries may be summarised as follows:—

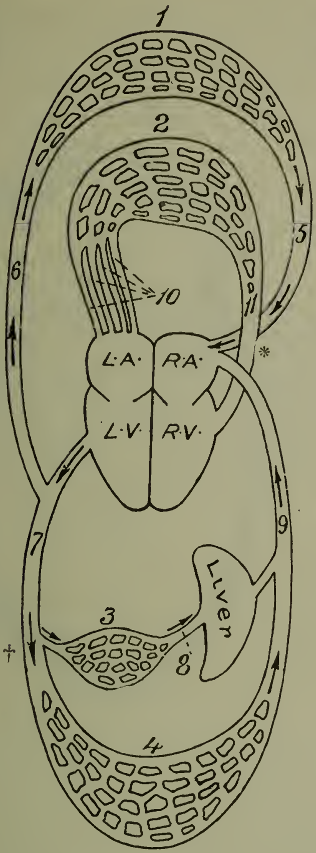
1. In the pulmonary capillaries (lungs) the loss of carbonic acid, water, and heat and the gain of oxygen.
2. In the systemic capillaries generally the loss of oxygen and nutriment and water. The gain of carbonic acid and other waste matters and heat.
3. In the capillaries of the alimentary canal—chiefly the gain of nutriment.
4. In the capillaries of the kidneys and skin. The loss of waste matters (other than carbonic acid) and water, and in the skin also the loss of heat.

But we have seen that in no part of our bodies does the blood come into actual contact with the tissue elements, for it is contained within a system of closed tubes—the blood-vessels. How, then, does this interchange of material between the blood and the tissues come about? The walls of the capillaries are so thin that much of the fluid part of the blood (the plasma) filters through them and fills the minute interstices around the capillaries themselves and between the individual tissue elements, so that these are entirely surrounded and are bathed by fluid. Not only the plasma, but many of the colourless blood corpuscles also find their way out of the capillaries into these spaces. This fluid which thus escapes from the capillaries is called the lymph. It is a little more watery than the blood plasma, but otherwise precisely resembles that, and "may be defined as diluted blood minus the red corpuscles." Now this lymph acts as middleman between the tissues and the blood. It receives on the one hand from the blood oxygen gas and food, and on the other hand from the tissues carbonic acid and other waste matters, and to the blood it gives what it receives from the tissues, while it gives to them what it receives from the blood. But this lymph also continually circulates, and finds its way back again to the blood. It does so by means of a series of vessels which are called the lymphatic vessels. These lymphatic vessels convey the lymph into a main lymphatic tube (the thoracic duct) which lies beside the backbone in the abdomen and thorax, and empties its contents into one of the large veins in the neck; on its way to the thoracic duct, the lymph passes through several glands which are called lymphatic glands. We need not here inquire into the function of these glands.

It sometimes happens, generally in cases of heart or kidney disease, that more fluid exudes through the capillary walls than the lymphatics are able to remove. In these cases the tissues become waterlogged and the part swells. Such a condition is known as dropsy.

The Blood Circuit.

We must now trace the course which the blood follows during its circulation or journey from the heart, through the arteries, capillaries, and veins, back again to the heart (fig. 12). We shall find that during a complete circuit the blood passes through the heart twice—once on the right side of that organ and once on the left. In tracing this journey it does not matter at what part of the circulation we begin, but it will be most convenient to start with the venous blood which is coming from



The left side of the heart deals only with arterial blood.

The right side of the heart deals only with venous blood.

FIG. 12.—DIAGRAM OF THE BLOOD CIRCUIT.

1. Capillaries of Head and Arms. 2. Pulmonary Capillaries (Lungs). 3. Capillaries of Stomach and Intestines. 4. Capillaries of Body. 5. Superior Vena Cava: Brings blood from head and arms. 6. Branch of Aorta. 7. Aorta. 8. Portal Vein. 9. Inferior Vena Cava: Brings blood from all parts of the body except head and arms. 10. Pulmonary Veins: Two from each lung. 11. Pulmonary Artery: Carries blood from right ventricle to lungs.

* From the right ventricle through the lungs to the left auricle is the Lesser or Pulmonic Circulation.

† From the left ventricle through the general capillaries of the body to the right auricle is the Greater or Systemic Circulation.

the various systemic capillaries towards the right side of the heart. This blood, as we know, is gathered up by the veins and it is finally collected into two large venous channels. One of these is called the superior, the other the inferior vena cava.* The former contains the blood which has passed through the capillaries of the head, neck, and upper limb, the latter, that from the remaining parts of the body. These two veins pour their blood into the right auricle. When this chamber is filled with blood its walls contract and its contents (venous blood) are driven through the tricuspid opening into the right ventricle (fig. 13). As soon as this chamber is full its walls begin to contract and the flaps of the tricuspid valve are forced together by the pressure of the blood in the contracting ventricle, thus closing the orifice between the auricle and ventricle (fig. 14). Since the blood is thus prevented from returning to the auricle, its only means of escape from the ventricle is through the pulmonary artery which carries it to the lungs. After passing through the pulmonary capillaries it is brought back to the left side of the heart by the pulmonary veins. Of these there are four, two from each lung. They pour their blood into the left auricle. On the left side of the heart the same sequence of events occurs as we have already seen on the right side, that is to say, as soon as the left auricle is full its walls contract and drive the blood (arterial) through the mitral opening into the left ventricle, and when this chamber is full its walls contract and, as in the case of the tricuspid opening, the mitral orifice is closed by the flaps of the mitral valve. The blood is then forced (under considerable pressure) into the main artery of the body, which is called the aorta, and is distributed by this vessel and its branches to the capillaries all over the body.

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* The plural of these words is venæ cavæ.

As soon as the contraction of the ventricle is over, its walls begin to relax again, and therefore there is a tendency for the blood in the aorta (or pulmonary artery) to be forced back into the ventricle. The returning blood, however, distends the three pouch-

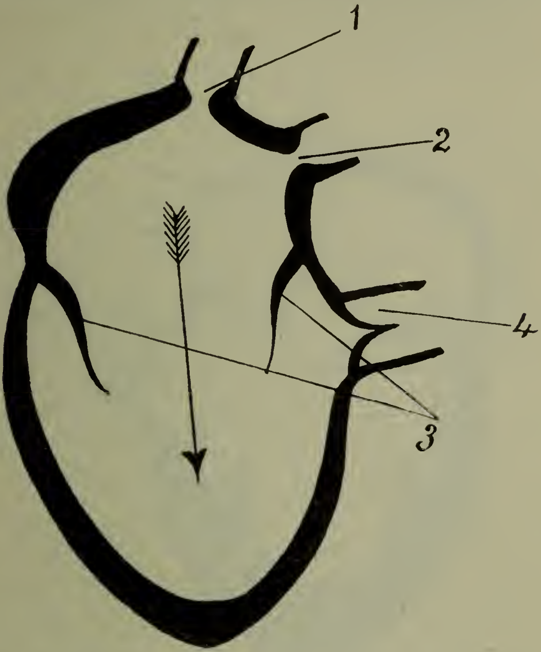

FIG. 13.—DIAGRAM OF THE RIGHT SIDE OF THE HEART DURING CONTRACTION OF THE AURICLE.

The arrow lies in the auriculo-ventricular opening.
1 and 2. The superior and inf. venæ cavæ. The openings of these vessels into the R. auricle, as of those of the pulmonary veins into the L. auricle, are not guarded by valves, but are closed during contraction of the auricle by muscular action, only partially shown in the diagram.
3. Flaps or cusps of the tricuspid valve—open to allow the blood to pass from the auricle into the ventricle.
4. The origin of the pulmonary artery showing the semi-lunar valve closed to prevent the blood from returning to the ventricle while that chamber is being filled from the auricle.

like (semi-lunar or half-moon) valves, which, as we have seen, surround the origin of the aorta and pulmonary artery in the ventricle, causing their edges to meet in such a manner as to completely close up the orifice and thus prevent the blood from finding its way back to the ventricle.

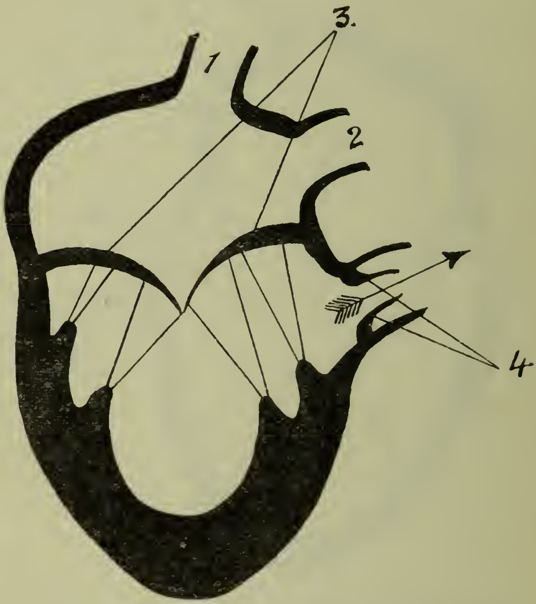

FIG. 14.—DIAGRAM OF THE RIGHT SIDE OF THE HEART DURING CONTRACTION OF THE VENTRICLE.

1 and 2. The sup. and inf. venæ cavæ.
3. The flaps or cusps of the tricuspid valve—closed to prevent the blood returning from the ventricle to the auricle.
The arrow lies in the origin of the pulmonary artery.
4. The cusps of the semi-lunar valve, now open to allow the blood to pass out of the ventricle into the pulmonary artery.

The right side of the heart deals only with venous blood, whereas the left side is concerned only with arterial blood. All the arteries in the body convey arterial blood from the heart except the pulmonary artery which, as we have seen, carries the venous blood from the heart to the lungs. So with regard to the veins—all these vessels carry venous blood except the pulmonary veins which bring arterial blood from the lungs to the heart.

That portion of the blood-current which extends from the right ventricle through the lungs to the left auricle is called the pulmonary circulation; in it, as we have just seen, arterial blood is contained within the veins and venous blood within the arteries. That portion which extends from the left ventricle, through the vessels of the tissue generally back to the right auricle, is known as the systemic circulation, in it the arterial blood is contained within the arteries while the venous blood flows in the veins.

The Portal Circulation.—There is one vein in the body which differs from all the others in that it ends after the manner of an artery by dividing up into a series of small branches and capillaries. This vein is called the portal vein. It collects the blood from the walls of the stomach and intestines as well as from the pancreas and spleen, that is to say, the blood which contains the newly absorbed nourishment. It passes to the liver and divides up within that gland into a series of capillaries from which the blood is again collected by another vein (the hepatic vein) through which it passes into the inferior vena cava. The portal circulation is merely a part of the systemic circulation and its purpose is that the nourishment coming from the alimentary canal may be brought into contact with the cells of the liver before it is thrown into the blood-stream. Another peculiarity about this portal vein is that it contains no valves, in which it resembles the pulmonary and cerebral veins.

The Pulse.—The different chambers of the heart on the right and the left side contract together—that is to say, the two auricles contract at the same time, and immediately after these, the two ventricles; there is then a slight pause, during which the auricles are being again refilled by the blood which is pouring into them from the veins. At each beat of the heart the same amount of blood is discharged from the left ventricle as from the right.

It will now be easily understood that the blood in the arteries is periodically augmented by the sudden discharge into them of the contents of the ventricles, and that thereafter no blood is received into them until the occurrence of the next ventricular contraction. Hence the blood in the arteries flows in waves, each wave distending the elastic walls of the arteries as it passes along.

It is this wave which constitutes the pulse, and the rapidity of the pulse therefore indicates the rapidity of the heart-beat. This varies at different ages. In young children the pulse beats at the rate of about 140 times a minute, and gradually diminishes until adult age is reached, when it averages 72 per minute in a man and about 80 in a woman. In old age it again becomes more rapid. The rate at which the heart beats, and therefore also, of course, the rate of the pulse is increased by muscular exertion, mental excitement such as is caused by sudden and unexpected pleasure or sorrow, fright, etc., etc., the taking of food—various drugs, especially alcohol—and increased temperature (fever); on the other hand violent mental emotions will sometimes cause the heart to stop beating. This is the cause of death when one is said to die of fright or sudden grief.

It is necessary to explain here that the blood flows much more rapidly in the larger arteries than in the smaller arteries and capillaries. The reason of this is that, although, as the arteries divide up, each resulting branch is individually smaller than the vessel from which it arose, yet the number of them is so enormously increased that the total capacity of the minute arteries and capillaries is much greater than that of the larger arteries. One may compare the blood course from the aorta to the capillaries to that of a river which gradually widens out towards its mouth. In the narrow upper reaches of the river the stream is rapid, and as it widens out towards its mouth it flows along more and more slowly. So greatly is the blood channel increased in area in the capillaries that the pulse wave is here altogether lost, and the blood flows through them in one continuous steady stream. As the capillaries unite and form the minute veins, and these again the larger ones, the rapidity of the blood current necessarily again increases as the total blood channel becomes gradually narrowed down; but the current in the larger veins is never as rapid as that in the larger arteries, as the capacity of these veins is greater than that of the larger arteries. Again, since the pulse wave is lost in the capillaries, there is, of course, no pulse in the veins, the flow of blood in these vessels being continuous and not jerky.

The blood of any individual may be regarded as being always the same in total amount. The quantity, however, which circulates through any particular organ varies very greatly in amount from time to time, depending upon the requirements of the organ. When we are using our muscles, as in walking or cycling, the quantity of blood flowing through them is much greater than when they are at rest; so when we are thinking our brains receive more blood than is the case when we have nothing to think about; and after taking a meal, while in other words we are digesting our food, the blood supply to the various parts of the alimentary canal is increased. The amount of blood which is supplied to any of our organs is under the control of the nervous system, and the regulation of the supply is brought about by the involuntary muscular fibres which, as we have already seen form, in part, the walls of the blood-vessels, and especially of the smaller arteries. When an organ requires much blood, these involuntary muscular fibres relax, and consequently the small arteries become wider, and so allow a greater amount of blood to pass through them. When the amount of blood required becomes less these fibres contract, and so diminish the calibre of the small arteries, and thus lessen the amount of blood passing through them. The act of blushing depends upon the same mechanism. We all know that in certain emotional states the amount of blood in the skin of the cheeks varies. If the state is one of shame the cheeks become red (blush), while those who give way to passionate rage often become blanched and pale—white with rage as we say. In blushing an impulse travels from the brain through the nerves which supply the involuntary muscular fibres contained in the small arteries of the cheeks, with the result that these relax, while during a fit of passionate rage the impulse which travels to these fibres causes them to contract so that the amount of blood passing through them is greatly diminished. It will be more easy to understand the nervous control of the blood-vessels when we come to speak of the nervous system.

6. THE DIGESTIVE SYSTEM.

During the whole period of life our tissues are always doing work. The work which a tissue does (energy) is, of course, its own special function. For example, the muscles produce motion, the brain thought, the various glands in the body their own particular secretions, etc., etc. But the performance of work entails waste of substance, and depends upon oxydation or burning. Now, whenever anything is burned—wood or coal, for instance—certain events follow with which we are all familiar. Heat is produced, while the coal or wood gradually disappears, passing away as smoke or ignited gases (flames). After the process is complete some ashes remain behind, which differ altogether in appearance, etc., from the original coal. A similar process may be said to occur in our tissues; the substances of which they are composed are continually undergoing oxydation, or in other words, are being slowly burnt; and as a result of this heat and various waste matters (ashes) are produced, while the materials of which the tissues are composed are used up. The greater the amount of work done the more rapid is the burning, and so the greater is the amount of heat and ashes produced; and therefore, of course, the greater also is the wasting or wearing out of the material. Our tissues are therefore continually losing substance, and hence as long as life lasts they require to be replenished and fed. We all know that if we cease to eat we become thin and waste away, and ultimately die of starvation.

We have already seen that the food is carried to the tissues from the alimentary canal by the blood. Before the food can be absorbed into the blood it must undergo many changes so as to render it soluble and absorbable. These changes are accomplished by the process of digestion. As we shall see immediately, the secretions of innumerable glands are poured into the alimentary canal. Some of these glands lie outside the digestive tube and their secretions are conveyed into it by means of ducts or channels, for instance, the salivary glands and the liver and pancreas; others are minute structures which lie embedded within the mucous membrane which lines the interior of the tube throughout its whole extent. The food as it passes along the alimentary canal is brought into contact with and is acted upon by these various secretions or digestive juices which dissolve the solid parts and reduce them to a condition which enables them to be readily absorbed into the blood.

By the process of digestion then, the various foods which we take are broken down and dissolved so that the particles (molecules) of food which are actually absorbed into the blood differ widely in many respects from those which we actually eat. If we take a piece of muscle (ordinary lean meat—mutton or beef) as an example, we find that this is crushed and torn to pieces by the teeth (mastication) and is, after being swallowed, reduced to a soluble state by the pepsin in the stomach. No one would now recognise, by the ordinary methods of observation, that this solution was muscle. Yet all the constituents of muscle are there, and when these are carried to the muscles of our bodies by the blood, they are again built up into actual muscle tissue. This latter process whereby the food particles or molecules as they exist in the blood are again converted into the material of the tissues, muscle, bone, brain, etc., etc., is known as the process of assimilation, and is in every respect as important a process as that of digestion. It is, then, by the process of assimilation that the worn-out tissues are renewed. It is, perhaps, not easy to understand that we, like our clothes, are always wearing out. Our tissues do not assume a shabby appearance, nor do they wear into holes, because as fast as they wear out the worn parts are repaired by assimilation. The processes of destruction and repair are being carried out at one and the same time. While we are young and growing, assimilation is in excess of the destruction or disintegration, and hence the total bulk of the body increases. After we are fully grown the two processes are equal in amount and we maintain a more or less fixed bulk or weight. As we grow old, or when attacked by various diseases, the destruction is in excess of assimilation and we lose weight and become thin. This process of assimilation is dependent for its proper performance, among other things, upon healthy nervous impulses received by the tissues through the nerves from the brain ; and hence it is that we frequently find that patients suffering from brain disease, especially general paralysis, waste away to mere skeletons although their appetite may be almost voracious.

The Classification of Foods.—The subject of the chemical composition of the tissues is a very complex and difficult one, with which we need not concern ourselves here. It is necessary to explain, however, that there are certain chemical elements in our tissues which must be supplied to them in the food we eat. Of these, four which enter into the composition of organic foods (foods, that is to say, which are derived either from animals or plants) are all important. They are oxygen, hydrogen, carbon, and nitrogen. In order that life may be sustained these four elements must exist in the food we eat in certain definite proportion. In addition to these we require certain minerals which exist in the food in the form of salts.

However varied may be the articles of food we take, they may all be grouped according to their chemical composition under four heads, which are:

1. *Nitrogenous or Albuminous Food-stuffs.*—These foods are compounds which contain all the four elements mentioned above—namely, oxygen, hydrogen, carbon, and nitrogen. As examples of this class of foods may be mentioned all kinds of lean flesh, such as mutton, beef, veal, chicken, fish, etc., and also the white of eggs and cheese.

2. *Fats.*—These contain no nitrogen, but are compounds of the other three elements, oxygen, hydrogen, and carbon. The fat portion of meat, suet, lard, butter, and the yolk of eggs, are examples of this class of foods.

3. *Starches* and *Sugars.*—These, like the fats, contain only oxygen, hydrogen, and carbon, but in

CLASSES OF FOODS.

1. Nitrogenous (meat, &c.).
2. Starches and Sugar.
3. Fats.
4. Salts.
5. Water.

DIGESTIVE JUICES.

1. Saliva.
2. Gastric Juice.
3. Bile.
4. Pancreatic Juice.
5. Intestinal Juice.

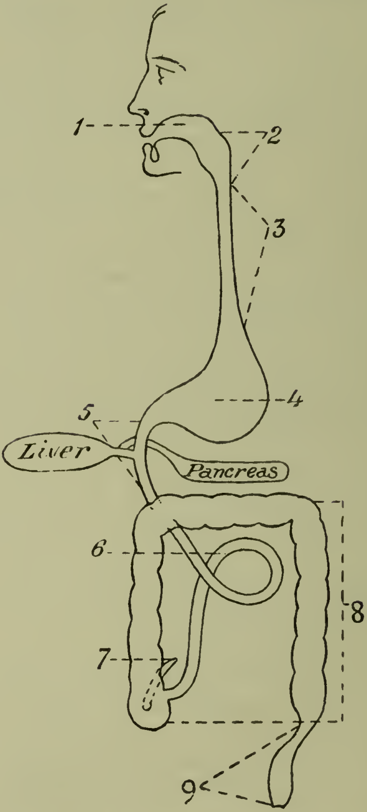

FIG. 15.—DIAGRAM OF THE DIGESTIVE APPARATUS.

1. Mouth: Food masticated and mixed with secretion of salivary glands (saliva) which changes starches into sugar. 2. Pharynx: Walls contain voluntary muscle. 3. Œsophagus: Walls of this and all remaining parts of alimentary canal contain involuntary

different relative proportions. They form a most important class of foods. Wheat flour (bread), cornflour, rice, potatoes, cane sugar, etc., are examples.

4. *Various Mineral Salts* and *Water.*—Water enters so largely into the composition of the body (it constitutes about two-thirds of the entire weight) forming the bulk of the blood and lymph that we require to take very considerable quantities of it. Much of the solid food we eat contains large quantities of water, especially some vegetables, such as turnips and fruits. In the body, water acts as a solvent, and carrier, and by its agency, many waste products are removed as in the urine and sweat. The mineral salts include common table salt (chloride of sodium), salts of potassium, calcium (lime), and iron, and many others.

Let us now make some inquiries into the nature and arrangement of the organs we possess for dealing with these food-stuffs, and learn what we can of the manner whereby the changes in them necessary to render them soluble are brought about.

The Anatomy of the Digestive System.—This must include a brief description of the alimentary canal, and also of those glands, the salivary glands,

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muscle. 4. Stomach: The mucous membrane contains the peptic glands which secrete pepsin. This dissolves nitrogenous foods, converting them into peptones. 5. Duodenum: This part of the small intestine receives the secretions of the liver (bile) and pancreas (pancreatic juice). The pancreatic juice changes starches into sugar and nitrogenous foods into peptones, and it emulsifies fats. The bile assists the pancreatic juice in emulsifying fats. It also facilitates the absorption of fats into the lymphatics of the intestine. 6. Small Intestine: A tube about 21 feet long. Its mucous membrane contains glands which secrete the intestinal juice. This continues to carry on the process of digestion, and probably acts like the pancreatic juice but more feebly. 7. Appendix. 8. Large Intestine or Colon: No further digestion takes place after the food leaves the small intestine, although absorption still continues during its passage through the colon. 9. Rectum.

N.B.—The products which result from the digestion of starches (sugar) and nitrogenous foods (peptones), also the water we drink and the soluble salts of the food, are absorbed directly into the blood vessels (capillaries) of the stomach and intestine, but the fats enter the intestinal lymphatics.

the liver, and the pancreas, which, although they lie outside the digestive tract, pour their secretions into it.

The Alimentary Canal is a tube, in all about 30 feet long, which passes through the body (fig. 15). It commences at the mouth and terminates at the anus. Its walls are composed of three distinct coats or layers. Throughout its whole extent the inner surface of the tube is lined with mucous membrane. Outside this is the muscular coat, composed of layers of involuntary muscle fibres, and covering this coat, in the abdominal portion of the alimentary canal, is a very thin, delicate, glistening membrane called the peritoneum. It is this membrane which becomes inflamed in the disease known as peritonitis. The peritoneum also lines the inner surface of the walls of the abdomen.

Mucous Membrane is found in other parts of the body besides the alimentary canal—for instance, in the air passages, as we shall see when speaking of the respiratory system, and in the bladder, etc. At the lips the general characters of mucous membrane may be compared to those of the skin. It forms a much softer and more delicate covering than the skin, and its surface is kept continually moist by the secretion of a slightly viscid fluid which is poured out from innumerable minute glands (the mucous glands) which are embedded within it. In addition to these glands it contains a very large number of blood-vessels, its red colour being due to this fact. In the stomach and intestines the mucous membrane contains, in addition to the ordinary mucous glands, many special glands which secrete the digestive juices.

The Mouth is the cavity into which the food is received. It is when closed almost, if not entirely filled up by the tongue, which lies upon the floor of the cavity. The tongue is a mass of muscular tissue which is covered by mucous membrane. Within this mucous membrane there end the special nerves of taste. But besides being the organ of taste, the tongue has other functions. It is very sensitive, so that so slight an object as a hair can easily be detected by it; and hence, if any hard or sharp object enter the mouth with the food, such as a small fish bone, for instance, the tongue gives warning of the fact, and so enables us to remove it from the mouth. In the first stage of the act of swallowing, the tongue, as we shall presently see, plays a very important part; and lastly, it is by means of the movements of the tongue (and lips) that we pronounce many of our letters; hence we find, when the tongue and lips become paralysed, as they do in general paralysis, for instance, that the patients have great difficulty in pronouncing many of their words and in starting the act of swallowing.

The entrance of the mouth is guarded by the lips, while its sides are formed by the cheeks. Its roof constitutes the palate. The front part of this is called the hard palate, for it is composed of bone covered by periosteum and mucous membrane. But the hinder part of the palate consists of muscle, covered by mucous membrane, and this part is known as the soft palate. The central portion of the soft palate is prolonged into a pendulous tassel called the uvula.

At the back the mouth is continuous with the pharynx or throat, and on each side of the passage between the two is a gland called the tonsil.

Immediately within the lips and cheeks are the teeth, arranged in two semi-circles, an upper and a lower semi-circle. They are fixed into the bony edges of the upper and lower jaws, which are covered by the gums, which consist of periosteum and mucous membrane. The teeth have different shapes, according to their uses. Those in front, both in the upper and lower jaw, have sharp, straight edges, so that when they are brought together, as in the closing the jaws, they cut through anything which may be lying between them, after the manner of a pair of scissors, hence they are called incisor teeth. There are four incisors in each jaw, and next to them comes on either side a pointed tusk-like tooth called the eye tooth or canine. Behind the canines are the premolars (two) and the molars (three). These latter ones have more or less flat crowns, and their function is to crush the food after the manner of millstones during the process of mastication. In the first set of teeth—the milk teeth, as they are called—there are only two behind the canines on each side in each jaw, so that in young children there are in all 20 teeth, whereas adults have in all 32.

The secretion of the salivary glands is conveyed into the mouth by means of ducts. Some of these glands lie in the floor of the mouth between the tongue and the lower jaw. Others lie just in front of and below the lobe of the ear (parotid glands). These latter glands swell up often to an enormous size in the disease called mumps.

The Throat or Pharynx is that part of the alimentary canal through which the food passes after it has left the mouth. Above and behind the palate it communicates with the back of the nose, while below it is continuous with the gullet. As we shall see later, it forms also a part of the air passages, since when we breathe the air passes through it on its way from the nose to the lungs. Its walls are composed of voluntary muscular tissue.

We shall presently see that the air tube or windpipe lies in front of the food passage in the neck. The orifice leading into the air tube is closed during the act of swallowing food by a complicated muscular movement, which converts it into a narrow chink, and so prevents the food from passing into the air passage. In front of the entrance to the air passage (glottis) there is a little leaf-like flap of cartilage covered by mucous membrane which is called the epiglottis. This projects upwards immediately behind the base of the tongue. In marsupial animals (kangaroos) this is an important structure, but it has no function in man.

The Gullet or *Œsophagus* is the name of the muscular tube which conveys the food from the pharynx to the stomach. It passes through the lower part of the neck into the thorax, where it lies beside the bodies of the vertebræ. The muscular fibres in its walls are entirely of the involuntary kind. After piercing the diaphragm it ends in

The Stomach, which is merely a peculiarly shaped dilatation or widening of this particular part of the ailmentary canal. In the mucous membrane of the stomach there are some special glands whose secretion contains a special ferment called pepsin. These glands are therefore called the peptic glands. The walls of the stomach contain a large amount of involuntary muscular fibres, which are arranged in layers. The region where the lower end of the stomach becomes continuous with the small intestine is called the pylorus, and here the tube can be closed by the contraction of a strong ring of muscular fibres. The stomach lies immediately beneath the diaphragm, and occupies, not the centre of the abdominal cavity, but the upper left-hand corner.

The stomach is the first part of the alimentary canal which has a peritoneal covering. All that part of the tube which lies above the diaphragm is without peritoneum. The peritoneum exists only within the abdominal cavity.

Continuous with the stomach is the small intestine. This commences at the pylorus, and terminates in the region of the right groin by joining with the colon or large intestine. The small intestine is the longest portion of the alimentary canal, and is about 21 feet long. It lies in numerous coils in the central portion of the abdominal cavity.

Throughout its whole extent digestive juices are poured into it from the numerous minute glands of its mucous membrane. The mucous membrane of this part of the gut is peculiar in that it is studded with an enormous number of minute finger-like projections called villi. Each villus contains blood-vessels and the commencement of a lacteal or lymphatic vessel, and it is through them that the chief absorption of the food takes place.

The first nine or ten inches of the small intestine—that is to say, that part which immediately follows the stomach—is called the duodenum, and into this portion are received the secretions of two large and important glands—namely, the liver and the pancreas. Their secretions are conveyed into the gut by means of ducts or channels, which, however, unite before entering the duodenum, so that the secretions of the two glands may be mixed by the time they reach the intestine.

The Liver is a very large gland, the largest in the whole body. It lies in the upper right-hand corner of the abdominal cavity immediately under the diaphragm. It is supplied with arterial blood by a large branch from the aorta, but, as we have already seen, it also receives all the blood which is gathered up from the stomach and intestines by the portal vein—that is to say, the blood which contains all the newly-digested food. In the portal capillaries this blood is brought into close relation with the liver cells, with the result that it undergoes some alteration; for these cells manufacture from it (1) glycogen, which is stored up in the liver for future use as a food, and of which we need not further inquire here; (2) bile, which is the name of the secretion of the liver, and which passes along the bile duct into the duodenum.

The Pancreas or *Sweetbread*, although much smaller than the liver, is still a large gland. It lies in a horizontal position across the back and upper part of the abdominal cavity, behind the stomach and duodenum. As we have seen, its secretion enters the duodenum with the bile. With the characters and functions of these two important secretions we shall have to deal when speaking of the processes of digestion.

The Large Intestine or *Colon* is so called, not because of its length, for it is much shorter than the small intestine, but because it is a much wider tube. It commences in the region of the right groin, and passes upwards on the right side of the abdominal cavity towards the liver. It then passes across the abdominal cavity and down the left side, and ends in the region of the left groin, where it enters the pelvis, by becoming the rectum. To the first part of this portion of the bowel there is attached a little worm-like hollow appendage a few inches long. This is what is called the appendix, and when it becomes inflamed it produces the condition known as appendicitis.

The Rectum is the last portion of the bowel. At its lower end it terminates in an orifice called the anus, which is surrounded by a strong circular muscle called the sphincter of the anus.

The Physiology of Digestion.—As soon as the food is received into the mouth it is crushed and torn to pieces between the teeth by the grinding action of the lower jaw. At the same time it is thoroughly mixed with the saliva. The salivary glands are stimulated by the presence of the food in the mouth, and during the act of mastication pour out an abundant amount of their secretion. Even the sight or smell of food, especially if it be of a savoury kind, will excite this secretion. This is so well known a fact that it is a common expression to say that any delicious morsel makes one's mouth water. The food is thus reduced to a soft pappy condition, and those parts of it which are readily soluble in water are dissolved. But as soon as the food comes into contact with the saliva, certain portions of it are at once attacked by that secretion, and through its agency undergo a chemical change. There is in the saliva a ferment (ptyalin) which is capable of converting the starchy foods, such as wheaten flour, etc. (which are insoluble) into a form of sugar (which is soluble).

This, then, is the main function or use of the salivary secretion—to convert the starches into sugar.

The food should be retained in the mouth for a considerable time in order that its mastication may be complete, for this is a very important part of the process of digestion, since the more finely the food is ground up by the teeth the more rapidly will it be acted upon by the gastric juice, and if it be swallowed only half masticated, portions of it may remain in the stomach in a semi-digested state and may pass on in this unprepared condition into the intestine, giving rise ultimately to discomfort or diarrhœa.

The Act of Swallowing.—When the process of mastication is complete the food is rolled into a ball by the tongue and is passed to the back of the mouth by the muscular (voluntary) action of the tongue acting against the hard palate. In other words, the bolus of food is simply squeezed backwards between the surface of the tongue and the palate. It is prevented from passing back into the nose (through the posterior nares) by the muscles of the soft palate. When it reaches the back of the tongue the bolus is grasped by the voluntary muscles of the pharynx or throat and at the same time the larynx (the upper portion of the air passages) is drawn up towards the base of the tongue, which in its turn is depressed to meet it. In this way the entrance to the air-passages (glottis) is closed and the food is prevented from passing down them. In various paralytic diseases such as general paralysis or some forms of paralysis resulting from localised brain-softening, and also after diphtheria, the soft palate and the muscles concerned in closing the glottis may be paralysed. In these cases the food is very liable to pass back into the nose or to get down into the air-passages and cause choking.

By the contraction of the muscular wall of the pharynx the food is forced downwards into the gullet. Up to this point the act of swallowing is purely voluntary. When the food reaches the gullet, however, the muscles which force it onwards are all of the involuntary kind, and the remaining stage of the act of swallowing is entirely involuntary. The bolus of food, having reached the gullet cannot be recalled by an act of the will, but must pass onwards into the stomach.

When the food reaches the stomach it is freely mixed with the *Gastric Juice.* The gastric juice is the secretion of the glands which lie in the mucous membrane of the stomach. It is an acid secretion, and its function is to dissolve or digest the *Nitrogenous portions* of the food—that is to say, the fleshy or meaty parts of our diet—converting them into *Peptones.* This particular action of the gastric juice depends entirely upon the presence in it of a ferment which is called *Pepsin.* We have seen that the presence of food in the mouth stimulates the activity of the salivary glands, so that saliva is abundantly poured forth. It is the same with the stomach. When the organ is empty its mucous membrane is relatively pale, and the secretion from it only scanty. On the entrance of food, however, the amount of blood which passes to the stomach is enormously increased, and the secretion from the peptic glands becomes abundant. This increased activity of the stomach commences as soon as the food enters the mouth, and is a nervous phenomenon.

In addition to pepsin, the gastric juice also contains another ferment called *Rennet*. Rennet curdles milk, and hence, when vomiting occurs soon after the patient has taken milk, the milk is always curdled.

Under ordinary circumstances, when the food has been thoroughly masticated, peptic digestion occupies a period of from three to four hours. During the whole of this time the involuntary muscles which, as we have already seen, exist in the walls of the stomach are slowly contracting and relaxing, so that the contents of the stomach are kept continually moving, and are thus churned up and thoroughly mixed. The food in this state is known as *Chyme*. While gastric-digestion is going on the chyme is kept in the stomach, and is prevented from passing on into the intestine by the contraction of the muscular fibres of the pylorus. When the process has been completed in the stomach these muscular fibres relax and the chyme passes through the pylorus into the first part of the small intestine or duodenum.

In the duodenum the food is mixed with the secretions of the liver (bile) and pancreas (pancreatic juice), and undergoes a complete change in its character. From being a yellowish acid fluid resembling pea-soup as the chyme is, it becomes milky and alkaline, and is now called *Chyle*. These changes are brought about chiefly by the action of the bile and pancreatic juice.

The *Bile* is a yellowish or reddish green bitter fluid of slightly sticky consistence. Alone it has but very small influence upon digestion, but when mixed with pancreatic juice it greatly assists this in some of its functions. When the bile, however, is prevented from entering the intestine, as may be the case in certain states where jaundice occurs, the motions lose their natural colour and become whitish or resemble clay; they also have a very foul odour and much gas is generated in the gut. Hence bile is thought to exercise some antiseptic property in the bowel. The only food-stuffs which are really acted upon by the bile are fats. These it partially converts into soap.

Pancreatic Juice is a colourless fluid much resembling saliva. It is a very powerful agent in digestion and attacks—

1. The starches, converting them, like saliva, into sugar.
2. Nitrogenous foods or albumins, and like the gastric juice, it converts these into peptones.
3. Fats. These it emulsifies.

The fats of our food all melt at the temperature of the body and assume a condition like oil. By the action of the pancreatic juice this oil is divided into minute globules, which float in the chyle and gave it its milky appearance. Fat in such a finely divided state is said to be emulsified. Milk is the best-known example of a natural emulsion, and we know that the fat of the milk (cream) takes some hours to separate out as a distinct layer on the top. Fats emulsify much more readily in the presence of small quantities of soap, and hence the emulsification of the fats of the food is hastened by the fact that the bile in acting upon the fats partially converts them into soap in the duodenum.

As the food passes on through the small intestine it is further mixed with the secretions which pour out of the glands which lie in the mucous coat of the gut (the *Intestinal Juice*). This also has some digestive power and probably resembles the pancreatic juice in its action, although it is comparatively feeble. With the small intestine the process of digestion ceases, and when the intestinal contents enter the colon no further digestive change occurs in it.

As in the stomach, the food in the intestine is continually being moved and churned about and, at the same time, forced onward towards the rectum by the alternate slow contraction and relaxation of the involuntary muscular layer of the intestinal wall.

After this short survey of the changes the various food stuffs undergo in the alimentary canal in order to render them fit for absorption, and of the agencies or juices whereby these changes are effected, it only remains now to add a few words to explain how the food thus prepared is absorbed and ultimately reaches the blood.

The mineral portions of the food (common salt, bicarbonate of soda or baking soda, phosphates of lime and magnesia, etc.) are readily soluble in the fluids of the mouth and stomach, and are absorbed together with the water directly into the blood without undergoing further change. The *sugar* which results from the digestion of starches, and the *peptones* which result from the digestion of nitrogenous foods are also absorbed directly into the blood. The absorption of these substances commences in the stomach, and continues as the food is passed on through the intestines as far as the rectum. We have seen that digestion ceases when the food leaves the small intestine, the products of digestion, however, still continue to be absorbed from the contents of the large bowel.

These digested matters (note that we are not speaking of fats now) pass into the blood which circulates in the capillaries of the mucous membrane of the stomach and intestines. From these capillaries, as we have already seen, the blood is collected by the portal vein, and is by it carried to the liver. After passing through this organ it is thrown into the general blood current on its way to the heart in the inferior vena cava.

The emulsified fats are not absorbed directly into the blood by the blood-vessels. These pass into the lymphatic vessels or lacteals of the intestines. We have seen that the mucous membrane of the small intestine is studded with an enormous number of minute finger-like projections called villi. Each villus contains, in addition to blood capillaries, the commencement of a little lymphatic vessel. Into this vessel the emulsified fats are received. They then enter the general lymphatic stream, and are conveyed by the thoracic duct into one of the large veins at the root of the neck.

Those portions of the food which, after being acted upon by the various digestive juices, still remain insoluble, pass on through the large intestine into the rectum, where they are discharged as fæces through the orifice of the anus.

7. THE EXCRETORY ORGANS.

We saw, when speaking of the digestive system, that in the production of energy—by which is meant heat, motion, thought, glandular secretion, etc., etc., the word energy being simply another term for the work done by an organ or tissue—the materials of which our tissues and organs are built are oxydised or slowly burned up, and as a result of this certain waste matters, comparable to the smoke and ashes of a furnace are produced. These waste matters are thrown by the organs which produce them into the blood, which acts as the general carrier in the economy of the body. But in order that health may be maintained the blood must be kept up to a certain standard of purity, and the waste matters must not be allowed to accumulate. The organs whose duty it is to remove these deleterious waste matters from the blood are spoken of as the *excretory organs*. They are the *lungs*, *kidneys*, and *skin*. We must now devote a little space to an inquiry into the nature of these waste matters, and of the arrangements with which we are provided to enable us to get rid of them.

Here it may be as well to explain the difference in the meaning of the terms *excretion* and *secretion*. Both are materials which are manufactured in the body, and both are the products of glands, but an *excretion* is a product which has no further use within the body—something which must be got rid of as speedily as possible, such, for instance, as the urine and the sweat—whereas a *secretion* is a glandular product which is capable of doing useful work within the body, which is, in fact, essential to the maintenance of life, such, for example, as the saliva, the gastric juice, or the pancreatic juice. But although one never speaks of the "excretion" of saliva or gastric juice, it is not uncommon to speak of the "secretion" of urine or sweat.

Nature is in the habit of economising, and hence we find that few of our organs have only one office or function to perform. Of the excretory organs the lungs and skin are no exception to this rule; they have other business to attend to over and above their excretory function. The kidneys, however, are exceptions, since their whole attention is occupied with the manufacture and excretion of urine.

A.—The Respiratory System.

We already know that the blood which circulates in the systemic arteries (arterial blood) differs remarkably in appearance from that which flows through the systemic veins (venous blood), and we have seen that this difference in appearance is dependent upon the relative amount of oxygen gas contained in these two varieties of blood—arterial blood being rich in oxygen, whereas venous blood, although still containing some of this gas, is relatively deficient in it. At the same time we know that venous blood contains far more carbonic acid gas than does arterial blood.

It follows, then, that at some part of the circulation these two gases—oxygen and carbonic acid—

must in the one case enter, and in the other leave, the blood, and from what we have learned already when studying the circulation, we know that this occurs while the blood is passing through the capillaries. This *interchange of gases* on the one hand *between the blood and the atmosphere* (that is, in the pulmonary capillaries), and on the other *between the blood and the living tissues* (that is, in the systemic capillaries) constitutes the *Function* of *Respiration.*

Before we can properly understand the process of respiration and the mechanism whereby we breathe, it is necessary to know something of the physical properties of the gaseous envelope which surrounds the whole world, and which we call the atmosphere. It is composed of a mixture of certain gases, and by its weight exercises a considerable pressure upon the surface of the globe, which may be looked upon as the bottom of a vast ocean of air. We may say that it is somewhere about 40 miles deep, and that beyond this, out into the unfathomable abyss of space, there is nothing but the theoretical ether. We human beings are therefore living at the bottom of this vast ocean which presses upon us with an enormous weight (equal to 15 lbs. on every square inch of the body's surface); but as this weight is equally distributed all over our bodies it is not appreciated by us.

Since, however, the pressure of the atmosphere is so great, it follows that every hollow space which is not occupied by some more tangible material—some solid or fluid substance—must be filled with air, or otherwise it would be crushed in. In other words, when we say that a box or a bottle is empty we really mean that it is filled only with air—it must contain air, since a vacuum or space which does not contain even air does not exist in nature, and can only with great difficulty be produced artificially.

As to the chemical composition of the atmosphere, it is sufficient for our purpose here to say that it is a mixture of three gases, of which one only is all important. This is *Oxygen.* It is for the purpose of getting oxygen into our bodies that we breathe. We cannot exist without oxygen. It is through the chemical union of oxygen with the elements of the tissues of our bodies, and of the food we eat (especially, though not only, the carbon), that all forms of energy or work are produced, and the same chemical process—oxydation—is the origin of heat. When a fire burns in the grate the heat which is produced is the result of oxydation of the coal. In like manner the heat of our bodies is the result of oxydation of the materials of which our tissues are composed, and the whole object of the function of respiration is to provide our tissue elements—the cells which in countless myriads build up our bodies—with oxygen, and to remove from them the carbonic acid which results from the oxydation of the carbon which exists in them. But if we breathed pure undiluted oxygen, the materials of our tissues would very soon be burned away; we should, in fact, live too fast. This is prevented because oxygen in the air is diluted with another gas which chemically is quite inactive. This second gas is called *Nitrogen.* It exists in the atmosphere apparently simply for the purpose of diluting the oxygen than which it is found in much larger quantities. Roughly, there is rather more than three and a half times as much nitrogen in the air as oxygen.

When dealing with the subject of alimentation and food we saw that our tissues are composed of certain chemical elements, of which the chief are oxygen, hydrogen, carbon, and nitrogen, and we learned then that these elements must be present in the food to supply the tissue waste which life entails, and to build up our bodies in the process of growth. Now, although all classes of food contain oxygen, we require so much of this element that it is quite impossible to meet the demands upon it by the food alone, and so we take it in its free state from the atmosphere. It might at first be thought that in like manner the demands for the supply of nitrogen could also in part be met in this way since with every volume of oxygen we inhale, we draw into our lungs more than three times the amount of nitrogen; but this is not so. Free nitrogen—that is to say, nitrogen not in chemical combination with some other chemical element—cannot be dealt with by our tissues in the process of assimilation, and the whole of the nitrogen required must be supplied in the form of nitrogenous food.

The third gas which is found in the air is carbonic acid. This in pure fresh air, such as is found among the mountains and at sea, exists only in very minute quantities, but in cities, where the air is smoky, or in buildings where many people are congregated, such as in church or the theatre, it is much more prevalent. In a hundred volumes of pure air—say a hundred bushels or a hundred pints or a hundred cubic feet—about 21 of these volumes would represent the amount of oxygen, and the other 79 would be nitrogen, whereas the amount of carbonic acid would only be 1-25th of a volume, or, stated in decimals, .04. Hence in speaking of the quantity of these gases in the air, we say that 21 per cent. is oxygen, 79 per cent. nitrogen (roughly), and .04 per cent. is carbonic acid.

We may now turn our attention to the function of respiration and the anatomical and mechanical arrangements by which it is brought about. In doing so we will arrange the matter under the following headings:—

1. *The organs of respirations* which include the *air passages* and the *lungs*.
2. The formation of the *air-tight box* or *chest cavity* (thorax), in which the lungs are contained.
3. The *act of respiration* and its stages.

4. The *mechanism* of *respiration.*

5. We must renew our acquaintance with the respiratory function of the blood.

6. We must note the differences between the *air we inspire* and *that which* we *expire.*

I. *The Organs of Respiration.*—The air passages are (1) *The Nose.* We normally breathe through the nose, and not through the mouth. As the air passes through the nose it is led over a considerable surface of mucous membrane which lines the interior of this as well as the other portions of the air passages. It is thus warmed, and much of the dust which is always present in the air adheres to the mucous secretion in the nose, and is thus prevented from entering the lungs. The nose communicates behind with (2) the pharynx by two openings called the posterior nares, which open into the pharynx above the soft palate. (3) The Larynx (fig. 16).—This is that portion of the air passages which contains the vocal cords. Its walls are made chiefly of pieces of cartilage, more or less movable on each other and connected together by membranes and muscles. It forms the prominence in front of the neck immediately below the chin, commonly called "Adam's Apple." The mucous membrane lining the larynx is arranged so as to form a sharp, straight, and slightly stretched fold on either side which runs from before backwards. These sharp edges are the vocal cords. They lie parallel with one another, leaving a narrow chink between them through which the air passes. This narrow chink is called the *glottis.* It is closed during the act of swallowing in the manner we have already seen. The epiglottis projects upwards behind the tongue immediately in front of the glottis. During the swallowing of fluids it may help to divert the stream to each side of the opening of the glottis. (4) *The trachea or windpipe* passes through the neck into the thorax. Its walls are composed of incomplete hoops of cartilage, which are connected together by an elastic

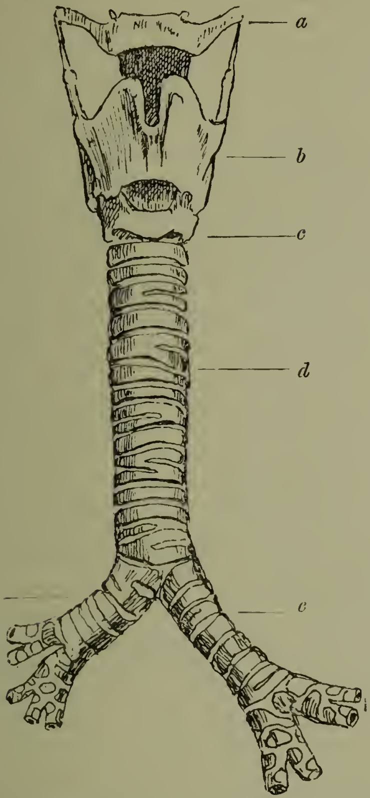

FIG. 16.—FRONT VIEW OF LARYNX AND TRACHEA.

a, hyoid bone; *b*, thyroid cartilage; *c*, cricoid cartilage; *d*, trachea; *e*, bronchi.

membrane. A piece of the hoop is wanting at the back, so that its posterior wall is composed only of membrane. The trachea lies in front of and against the œsophagus. After entering the thorax the trachea divides into two branches. (5) The *Right and Left Bronchus*, each of which passes into the lung of its own side. Within the lung each bronchus divides up into a great number of branches, which become smaller and smaller as they pass deeper and deeper into the substance of the lung. These are called the *Bronchioles* or *Bronchial tubes*. Before terminating in the air cells, as we shall presently see, they become so minute that they cannot be seen without the aid of a microscope. The walls of the bronchi and of their larger branches contain cartilaginous hoops like those of the trachea, but in the smaller air tubes (bronchioles) these disappear, and their walls are entirely membranous.

The Lungs are two in number. They together completely fill the cavity of the chest (except such parts as are occupied by the heart, the great blood-vessels, the trachea, and the two main bronchi and the œsophagus), and form, as it were, a perfect mould of the interior of this cavity. They are elastic, spongy organs, and, being filled with air, they are very light and float when placed in water. Each lung is more or less conical in shape, the smaller end or *apex* fitting into the narrow upper end of the thorax behind the clavicle and beneath the upper ribs. The broad end or *base* of the lung occupies the lower part of the chest, and rests upon the upper convex surface of the diaphragm. The outer surface of the lungs is everywhere in contact with the chest wall, their inner surfaces look towards each other and over-lap the heart, which lies between them. It is on the inner surface that the bronchus of each side enters the lung, and here also enter and leave the great blood-vessels which pass between the lungs and the heart—these are, as we already know, a branch of the pulmonary artery which conveys the venous blood from the right ventricle to the lungs, and two pulmonary veins which convey the oxygenated arterial blood from the lungs to the left auricle. This part of the lung where the bronchus and pulmonary artery enter, and the pulmonary veins leave it, is called the *Root* of the lung.

The surface of the lungs is everywhere covered by a closely adherent, thin, shining membrane called the *Pleura*. At the root of the lung on each side it is reflected on to the inner surface of the walls of the thorax, which it also completely lines. Thus each lung lies within a sort of bag, just as we have seen is the case with the heart, with this difference, however, that whereas the outer layer of the pericardium is a loose bag, the outer layer of the pleura is closely and firmly attached to the inner surface of the thoracic wall and the upper surface of the diaphragm.

Each lung consists of an enormous number of little elongated dilatations, whose walls are composed of an elastic membrane. These dilatations are the terminations of the minute bronchial tubes. They are like little elastic bladders, but their walls, instead of being smooth and even, are made up of numerous little indentations or sacs—*air cells*, as they are called—whose mouths open irregularly into the cavity of the dilatation. If it were possible to isolate one of these dilatations and blow it up with air it would look something like a bunch of grapes, only the different sacs would not be so distinct from one another as the individual grapes. The walls of the air cells are very thin, and are composed of a delicate and highly elastic membrane *which carries the capillary blood-vessels* into which the pulmonary artery pours its blood. The object of this arrangement is to bring the impure venous blood of the pulmonay artery into as close contact with the air as possible in order that it may gain oxygen from the air and get rid of the carbonic acid gas which it contains.

During its passage through the pulmonary capillaries the blood is separated from the air in the air cells only by the thin walls of the capillaries themselves and the epithelial lining of the air cells. These form a delicate membrane through which both oxygen and carbonic acid are, in common with all gases, enabled to pass by what is called the property of diffusion.

We see then that the air in the air cells of the lungs gives up its oxygen to the blood contained in the pulmonary capillaries, and receives from this same blood carbonic acid in exchange. It is obvious, therefore, that the air in the air cells would soon become so charged with carbonic acid and so deficient in oxygen as to be useless for the purposes of respiration if there were not some provision made to ensure its being frequently changed. This changing of the air in the air cells is brought about by the *movements* of *respiration.*

II. *The formation of the Chest Cavity.*—The lungs are contained within an air-tight box which we call the thorax. For our present purpose we may neglect the other contents of this box and say that it is entirely filled by the elastic lungs. Now the only means by which air can enter this box is through the air passages, which, however, communicate not directly with the interior of the box itself, *but with the lungs which it contains*; in other words, if air enters the box at all, it must do so by entering and distending the lungs.

The walls of the thorax are composed partly of muscle and partly of bone and cartilage, consisting, as already explained, of the ribs, the breast-bone, and costal cartilages, together with the muscles which clothe these bones and lie between them, while at the back of the cavity there are the twelve dorsal or thoracic vertebræ. The roof of the box through which passes the trachea is filled in by the tissues (muscles, fat, etc.) of the root of the neck, whilst its floor is composed entirely of the muscular diaphragm. The reason for the existence of all these arrangements we shall see presently when we come to deal with the *Mechanism of Respiration.*

III. *The Act of Respiration.*—This consists of three distinct phases, which follow each other in regular rythmical order. These phases are (*a*) the taking of air into the lungs or *Inspiration* followed immediately by (*b*) the expulsion of air from the lungs, or *Expiration*; and then there is (*c*) a *short pause*; after which inspiration is again repeated, to be followed in turn by expiration, and again a pause, and so on. In an adult at rest this compound respiratory act is repeated about 15 to 18 times in a minute. The larger the chest capacity of the individual the less frequently does he respire, and so in men the number of respirations per minute is usually rather less than in women. In children, for the same reason, the number is higher, being on an average from 20 to 25 per minute. The rate of respiration is increased by any muscular exertion, and various emotional states also greatly affect it. Both the rate and manner of breathing may also be affected by various diseases.

IV. *The Mechanism of Respiration.*—The act of inspiration depends upon the fact that the *cavity of the thorax is capable of enlargement* so that its total capacity may be increased, whereas expiration is dependent upon a *diminution in the size of the cavity*, and in addition the *elasticity of the lungs.* Now when the cavity is enlarged air must pass into it, since, as we have already seen, we are living at the bottom of an ocean of air which presses down equally upon every part of our body. The means whereby the capacity of the cavity of the chest is increased are:—(1) The Diaphragm.—This forms the muscular floor of the chest. When it is at rest it is arched upwards, forming a sort of dome-shaped roof to the abdominal cavity. The central part of the diaphragm is fibrous or tendinous, while the muscular contractile part is arranged around this, and is attached to the lower ribs, to the upper lumbar vertebræ, and to the lowest portion of the sternum. Hence when this muscular portion contracts or shortens the central fibrous part is drawn downwards towards the abdomen, and the vertical dimension of the chest is increased. (2) The Ribs.—Each pair of ribs forms, with the costal cartilages and the breast-bone, a hoop. These hoops are not set horizontally, but obliquely—that is to say, they occupy the same position relatively to the earth when we are standing upright, as a hoop which is resting against a wall, and not as one which is lying upon the ground. The ribs are jointed behind to the dorsal or thoracic vertebræ. This is the highest portion of the hoop, and if we continue our simile would correspond to that portion of the hoop which rests against the wall. Now by the action of certain muscles, the muscles of inspiration, as they are called, we are enabled to move our ribs in such a manner as to raise up the lower border of the hoop. During this movement the breast-bone is thrown forward, or further away from the spinal column, and so the horizontal dimension of the thorax is increased from before backwards. But by the same muscular action which raises the ribs they are also thrown outwards, so that the horizontal dimension of the thorax is also increased from side to side. As a consequence of the enlargement of the chest cavity in these directions—namely, vertically through the depression of the diaphragm and from before backwards and from side to side—by the lifting up of the ribs, air rushes in to fill up the increased space. We already know that the only way it can get in is through the air passages into the air sacs of the lungs which it distends and stretches.

At the end of the act of inspiration the muscles

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which have been concerned in enlarging the cavity of the chest relax, and as a consequence the diaphragm again becomes arched up into the chest by the pressure of the abdominal contents below it, and the ribs fall, partly by their own weight and partly by muscular action—the muscles of expiration. The elastic tissue of the lungs then comes into play and drives out some (not by any means all) of the air contained in the air sacs.

During ordinary normal respiration only a very small proportion of the total amount of air contained in the lungs is changed. At the end of an ordinary inspiration an average-sized chest will contain about 220 or 230 cubic inches of air; during expiration only the odd 20 or 30 cubic inches are expelled, leaving some 200 cubic inches still in the lungs. This 20 or 30 cubic inches of air which is inspired and expired during every respiratory act is called the *Tidal Air*. If we take a very full breath—a forced inspiration—so as to expand the chest to its greatest possible capacity we can draw in about 100 cubic inches more, and this extra amount is called the *Complimental Air*. In the same manner it is possible to force out about 100 cubic inches of air beyond the tidal air by making a forced expiration, and this air is called the *Reserve Air*. But even at the end of the deepest possible expiration there still remain in the lungs about 100 cubic inches of air, which it is quite impossible to force out, and this is called the *Residual Air*. The fresh tidal air which is taken into the lungs at every inspiration mixes with the air (reserve and residual) already contained within the lungs by diffusion, and so the carbonic acid which is continually being poured by the blood into the air in the air cells is carried away, and the oxygen which is taken from it by the blood is replaced, and a certain standard of purity is maintained.

V. The *Respiratory Function of the Blood.*—The blood which is brought to the lungs by the pulmonary artery is, as we already know, venous blood. The sole object of its passage through the pulmonary capillaries is that it may gather up oxygen in which it is deficient and get rid of carbonic acid with which it is surcharged. These gases, in common with all other gases, have the physical property of being able to pass through animal membranes, and therefore they are enabled to pass through the delicate membrane which constitutes the walls of the minute capillaries and of the air cells of the lungs. Now when oxygen enters the blood it at once combines with the hæmoglobin which, as we know, is the material which gives their red colour to the red blood corpuscles, forming what is called oxy-hæmoglobin, and at the same time it converts the dull red or purple colour of venous blood into the bright scarlet of arterial blood. The carbonic acid of venous blood is not carried by the corpuscles, but is dissolved in the plasma; from this it readily passes outwards into the air cells. During its passage through the systemic capillaries the reverse of these changes takes place—that is to say, the blood corpuscles lose oxygen (the oxy-hæmoglobin becoming again reduced to hæmoglobin), which passes out of the blood into the lymph which bathes the individual tissue elements, and carbonic acid passes from the lymph into the plasma of the blood.

VI. *Differences between Inspired and Expired Air.*—The air which leaves the lungs at every expiration differs from fresh air in many respects, and it cannot be too forcibly stated that air which has once passed through the lungs is no longer fit for respiration, and should never again be inhaled. Expired air contains slightly less oxygen than fresh air, and vastly (about 100 times) more carbonic acid. It also contains much more moisture. It is also hotter than the surrounding atmosphere. As the air passes out of the lungs through the air passages and mouth it carries with it some minute particles of organic matter. This may consist in part of some of the superficial cells from the lining membrane of the air passages themselves, but is no doubt chiefly composed of microscopic particles of food which cling to the teeth, gums, and walls of the mouth and pharynx at every meal. This organic matter which is thus expelled with every respiratory act floats about in the air, where it undergoes putrefaction, and produces the close, stuffy smell which is always found in badly ventilated rooms, churches, theatres, etc., which are occupied by human beings. When taken into the lungs it acts as a poison, and is sure, sooner or later, to give rise to ill-health.

B. The Urinary System

comprises the kidneys with their ducts (the ureters), and the bladder and the narrow channel (the urethra), which carries the urine from the bladder (fig. 17). The function of the kidneys is to excrete the urine.

The kidneys are two in number—a right and a left one. They are firmly fixed to the back of the abdominal wall in the region of the loins, one on either side of the spinal column. They are of a characteristic shape—something like that of a bean seed, and weigh, as a rule, about four ounces each. The inner side of the kidney, that which is nearest the spinal column, is depressed or concave in shape, and is called the Hilus. Here a large artery enters the kidney, and a vein leaves it (the renal artery and vein), and from the same part the ureter proceeds from each kidney down to the bladder. The ureters are comparatively long and narrow tubes. They are in contact with the back wall of the abdominal cavity down which they pass into the pelvis, where they enter the bladder in its posterior or hind part, each one separately.

The bladder is an oval bag, which lies within the pelvis. It is lined inside with mucous membrane, and its walls contain a large amount of involuntary muscular fibres. At the "neck" of the bladder there is an opening which leads into the urethra, and which is surrounded by a ring of circularly arranged muscular fibres (involuntary) called the sphincter of the bladder.

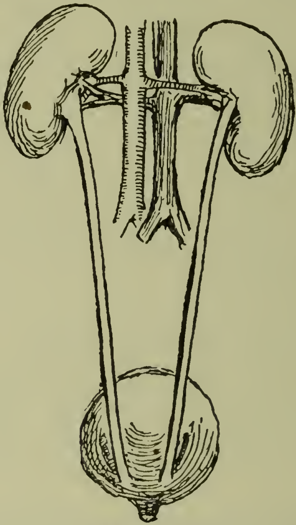

FIG. 17.—BACK VIEW OF KIDNEYS, URETERS, AND URINARY BLADDER.

The urine is constantly being excreted by the kidneys. From these glands it passes down the ureters into the bladder, which acts as a reservoir. It is retained in the bladder by the action of the sphincter muscle, which, when the bladder is full, may be relaxed by means of a nervous mechanism which is under the control of the will. The contents of the bladder then pass away through the urethra.

We have seen that carbonic acid, which is a gas, and is removed from the body by the lungs, is the result of the oxydation of carbon which exists in the food and tissues. Now, in like manner during the digestion and assimilation of nitrogenous foods, such as meat, fish, etc., and as the result of waste of our nitrogenous tissues, especially the muscles, certain solid waste matters are produced, the chief of which are urea and uric acid. These are removed from the blood by the kidneys, and are dissolved in the water of the urine. In addition to these the kidneys also remove from the blood various mineral salts.

The function of the kidneys, then, is the removal from the blood of

1. Water.
2. Certain solid waste matters, the chief constituent of which is nitrogen. These are urea and uric acid. Of the former about 500 grains, and of the latter 10 or 12 grains, are excreted in 24 hours.
3. Various saline matters, of which the chief are common salt and some phosphates and sulphates, chiefly of potassium and sodium.

Normal Urine is a pale yellow or straw-coloured clear fluid, of which about 50 ounces, or 2½ pints, are excreted in 24 hours. The amount, however, varies very greatly, according to circumstances, as we shall see more particularly in a later section. Its chief bulk is made up of water, which holds the other constituents in solution.

The following table shows its composition: —

Water.		
Organic Waste Matters containing Nitrogen	Urea	
	Uric Acid	Combined with Pot. and Sod. forming Salts (Urates)
Inorganic Salts	Common Salt (Chloride of Sod.) Phosphates of Pot. and Sod. Sulphates of Pot. and Sod.	

C. The Skin.

The skin is a tough, elastic membrane which forms the outer covering of the body. It is separated from the deeper tissues by the fat. It consists of two distinct layers. The outer one—that is to say, the one in contact with the air—is the cuticle or scarf skin; the deeper one is known as the cutis vera or true skin.

The Cuticle consists of many layers of closely packed cells, and forms a more or less horny covering for and protection to the true skin. The cells immediately on the surface may be regarded as being dead, and they are constantly being brushed off into the air. They are replaced by the new cells, which grow and are being pushed up, as it were, from the deepest part of the cuticle, that, namely, which is in contact with the true skin. In health this loss of the superficial cells of the cuticle is not noticeable, but in many diseased states, after scarlet fever and erysipelas, etc., and in many forms of skin disease, the cuticle may peel off in flakes or scales of considerable size.

The cuticle contains no structures, there are no blood-vessels, and no nerves in it; but it is pierced, as we shall presently see, by the ducts of certain glands and by the hairs.

It serves a purpose which is purely mechanical, its only function being to cover and protect the vascular and highly sensitive cutis or true skin beneath it.

The *Cutis or True Skin* is abundantly supplied with blood-vessels and nerves. From it grow the cuticle and nails, and within it are contained the hair follicles from which the hairs grow, and two kinds of glands—namely, the sebaceous glands and the sweat glands.

The *Hair follicles* may be described as little pits or sacs in the cutis, from the bottom of which the hair grows.

The *Sebaceous Glands* are arranged about the hair follicles, into which their secretion is poured. This secretion is of an oily or greasy nature, and gives to the hair its natural gloss. It also serves to keep the cuticle soft, and prevents it from becoming dry.

The *Sweat Glands* secrete the perspiration. The body of the gland lies embedded within the cutis, but the duct pierces the cuticle as a minute spiral tube, and opens upon the surface. These little openings are present in thousands all over the body, and constitute what are often spoken of as the "pores" of the skin.

The sweat consists chiefly of water in which are dissolved some solids; of these one-half is common salt (sodium chloride). It varies enormously in amount from time to time, and is, under ordinary circumstances, imperceptible, since it evaporates from the surface as fast as it is secreted. In hot weather and during violent muscular exertion it is secreted much more rapidly than it can evaporate, and therefore it collects on the surface of the skin and forms beads of fluid.

Arterial blood, as it passes through the capillaries of the skin, is not rendered venous, but retains its arterial characteristics. Some carbonic acid is in fact given off by the skin, and a small amount of oxygen is absorbed from the atmosphere by the blood in the cutaneous capillaries.

On account of the large amount of blood contained in the skin a great deal of the heat of the body is lost through it. Hence the skin plays a very important part in the regulation of the temperature of the body.

Certain of the nerves of the body end in the skin. These nerve endings when stimulated give rise to certain impressions, which are conveyed by the nerves to the brain, and are there interpreted as various sensations, such as that of touch, pain, heat, cold (common sensation).

Briefly stated, then, the functions of the skin are these: —

1. It is a covering for the body.
2. It is an excretory organ, removing from the body water and salts, as well as a very minute quantity of urea.
3. It is, although in man to a very trivial extent, a respiratory organ.
4. It plays a part in the regulation of the temperature of the body.
5. It is the seat of common sensation.

Immediately beneath the skin there is a layer of fat which varies very much in thickness in different individuals. This, under normal conditions, forms a sort of cushion all over the body, fills up the hollows, and rounds off the angles, and adds plumpness and grace to the outline of the body. It prevents to a large extent the loss of heat, and acts as a reserve of nourishment in case of need.

8. THE NERVOUS SYSTEM.

We have seen that the various organs or systems of organs in the body all depend very much one upon the other—each system has to do its own particular work for the common welfare of the whole organism. The blood is the agent through which the various organs of the body are brought into relation with one another, and which is affected directly by all the organs which we have up to the present been discussing—they all either give to it or take from it, and hence we cannot say that one system of organs is more important in the whole economy than another. The remaining system which we have to deal with is, however, in the nature of its functions, so high above all the rest, and occupies such a commanding position over them all, that we may certainly regard it as being the all-important one in man. This is the nervous system.

It controls and regulates the functions of all the other organs. It originates all muscular action. It governs and controls the movements of the heart and blood-vessels. It is through the influence of the nervous system that the various digestive juices are secreted, and that the movements of the alimentary canal are regulated. The act of respiration, the secretion of the urine and sweat, the growth of the various tissues of the body, and the assimilation of the food from the blood and the proper repair of damaged and worn-out tissues, the maintenance of the proper temperature of the body, etc., etc., all depend upon the healthy working of the nervous system. It also receives and interprets impressions or sensations from without the body, whereby we are brought into relation with the outer world and our fellow-creatures, and from within the body, whereby we are made cognisant of the condition of our own organs and tissues, and it is the seat of the mind.

The nervous system is built up of two kinds of tissue, which are called respectively the grey matter and the white matter. These two different kinds of tissue can easily be distinguished from one another by the appearance they present to the naked eye, and when examined with a microscope their differences are still more marked. As we shall see presently, the grey matter and the white matter occupy certain definite parts of the nervous system, and are not indiscriminately intermixed. Both forms of nervous tissue consist of certain nerve elements, which are bound together and supported by a delicate connective tissue called neuroglia. Those parts which consist of grey matter are spoken of as nerve centres, and their distinguishing peculiarity is that they are built up very largely of nerve cells (fig. 18). These nerve centres, however, contain many nerve fibres as well as nerve cells, the fibres passing from one cell to another, and thus connecting them with each other. The cells exist in different parts of the grey matter of the nervous system in all varieties of shapes and sizes, the most typical being somewhat large (larger than a red blood corpuscle), irregular, more or less angular masses of protoplasm. From their corners or angles there pass delicate branching nerve fibres to or towards other similar cells; while from one side of the cell there arises a larger unbranched process or fibre which, soon after leaving the cell, becomes covered with a white sheath. This fibre, with many other similar ones, goes to build up one of the cranial or spinal nerves. The white matter of the nervous system is composed entirely of these white unbranched processes from the nerve cells (held together and supported by neuroglia).

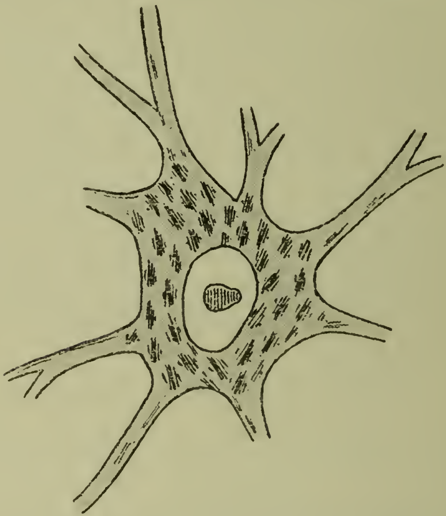

FIG. 18.—NERVE CELL, FROM THE ANTERIOR HORN OF THE SPINAL CORD.

Both the grey and the white matter are, of course, abundantly supplied with blood-vessels, for the nervous system cannot carry on its functions without an abundant supply of pure arterial blood.

Briefly, then, the nervous elements of the grey matter are nerve cells as well as nerve fibres, while those of the white matter are nerve fibres only. We shall presently see how these two varieties of nerve tissue are arranged in our bodies.

For the purposes of description the nervous system is said to comprise two sets of nerve centres and nerve fibres.

1. The cerebro-spinal or central nervous system.
2. The sympathetic system.

It must not be imagined that these are distinct from one another, for they are intimately connected together, and the dominating member of the partnership is the cerebro-spinal system, the sympathetic system receiving guiding influences, or, as we may say, instructions from the brain and spinal cord.

I. *The Cerebro-Spinal Nervous System.*—This comprises the brain and spinal cord, together with the nerves which arise from them. Those nerves which arise directly from any part of the brain are called the cranial nerves, while those which come from the spinal cord are called the spinal nerves.

The brain occupies the cavity of the skull, while the spinal cord is contained within the spinal canal in the backbone. The cranial nerves leave the skull by passing through holes in the bones which form its walls, while the spinal nerves pass out from the spinal canal between the different vertebræ.

Both the brain and the spinal cord are surrounded and enveloped by a series of membranes called the meninges. Of these the outer one (the dura mater) is a tough, strong, fibrous membrane which is closely attached to the inner surface of the bones of the skull, but lies loosely within the spinal canal. The inner membrane, called the pia mater, is closely attached to the surface of the brain and spinal cord, which it completely envelopes. It is a very thin and delicate membrane, but contains a large number of blood-vessels. Between the dura and the pia there is a certain amount of fluid which serves to support the brain and in which it, as it were, floats.* When any of these membranes or meninges become inflamed the disease which results is called meningitis.

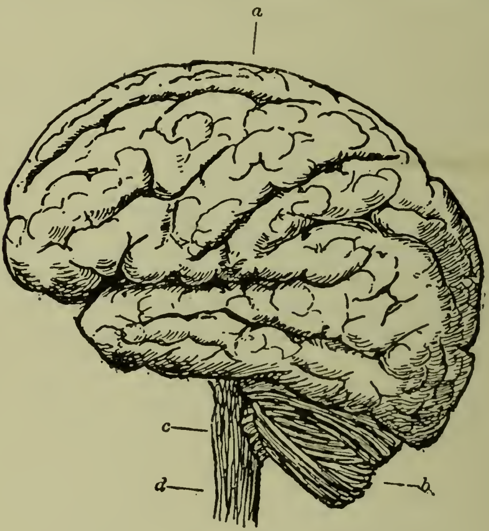

FIG. 19.—THE HUMAN BRAIN.

a, cerebrum; *b*, cerebellum; *c*, medulla oblongata; *d*, spinal cord.

The Brain.—When one looks at the human brain (fig. 19) it is easy to see that it may be roughly divided into three chief parts which differ obviously from one another in their shape and size and in the nature of their surfaces. These three parts are called—

---

* There is a third membrane called the arachnoid lying between the dura and pia, but for our present purpose, and for the sake of simplicity, it is unnecessary to include this in the general description.

1. The large brain or cerebrum.
2. The small brain or cerebellum.
3. The pons and medulla.

The total weight of the brain averages about, or a little over, three pounds, and is about five ounces less in women than in men.

1. The large brain or cerebrum, as its name implies, is by far the largest of these three divisions. It occupies the greater part of the skull cavity, and extends from behind the forehead backwards over the small brain or cerebellum, which it overlies and which, when looked at from above, it almost entirely hides, and its general outline corresponds with the vaulted interior of the cranial cavity. Running along its surface from before backwards there is a central fissure which dips deeply down into its substance, and divides it into two equal parts which are called the right and the left hemispheres. The surface of the hemispheres presents a very characteristic appearance, being composed of a number of irregularly arranged elongated, almost worm-like elevations which are separated from one another by depressions (fissures or sulci) into which dip prolongations of the pia mater. These elevations, which seem to twist and interlace with each other, are called the convolutions of the cerebrum, and their meaning is to give a greater extent of surface to the brain, which, as we shall presently see, is composed of grey matter. The greater the number of convolutions and the more intricate and apparently confused their arrangement the higher is the intelligence of the individual possessing them. Hence we find in the lower animals, such as fishes and birds, the cerebral surface is much smoother and the con-

volutions more simply arranged than in the higher animals, such as the apes and man and in the lower orders of man, such as the Hottentots and other savages, than in the white races. The convolutions are developed by education and training, and so increase in complexity with the growth and advancement from childhood to maturity, and they undergo some shrinkage as old age creeps on and brings with it the natural enfeeblement and simplicity of our second childhood. The two cerebral hemispheres are connected with one another by a broad, flat band of nerve fibres, which pass from one side to the other. This band of fibres (called the corpus callosum) lies at the bottom of the deep central fissure which divides the two hemispheres from one another. The internal arrangements of the cerebral hemispheres are somewhat complicated, and need not now occupy our attention.

2. The small brain or cerebellum is relatively to the cerebrum very much smaller in man than in the lower animals. It occupies the lower and hind portion of the skull cavity, and is, as we have already seen, quite overlapped by the posterior portion of the cerebrum. It, like the cerebrum, is composed of two equal and similar halves, but the depression which separates these from one another is comparatively shallow. Its surface is masked by numerous closely-set fissures which run more or less parallel to one another, giving this portion of the brain the appearance of being made up of a series of closely-packed layers.

3. *Pons and Medulla.*—The bridge (pons) is a bunch of nerve fibres which pass from side to side. It looks something like a small cushion. The bulb (medulla) is really the upper enlarged end of the spinal cord. It consists largely of nerve fibres on their way from the brain to the spinal cord, and *vice versa.* This part of the brain forms a sort of junction whereby the cerebrum and cerebellum com-

municate with each other, and both these with the spinal cord.

The spinal cord is an elongated rope-like mass of nervous tissue which is a continuation of the bulb. There is no definite alteration in the structure of these two parts which indicates where the one ends and the other begins; as soon as it passes out of the skull into the spinal canal the mass of nerve tissue ceases to belong to the bulb, and becomes the spinal cord. In the middle line, both in front and behind, the surface of the cord is indented by a fissure; both of these fissures pass towards the centre of the cord, but do not meet, but they almost cut it into two equal halves. Running through the centre of the cord there is a small canal which contains fluid (cerebro-spinal fluid), and which communicates with a series of cavities (the ventricles) in the bulb and great brain. From the sides of the cord there branch off from it the series of spinal nerves which pass out from the spinal canal between the vertebræ. Of these there are 31 pairs. Each spinal nerve arises from the cord by two roots (fig. 20), as they are called; these almost imme-

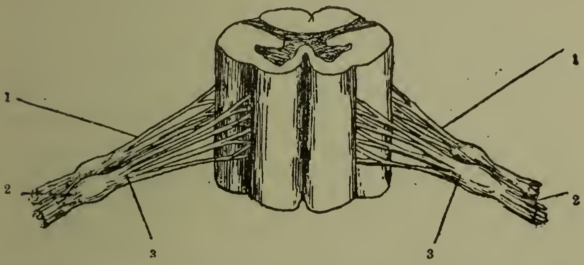

FIG. 20.—SECTION OF SPINAL CORD, WITH ROOTS OF SPINAL NERVES—FRONT VIEW.

1, 1, sensory root; 2, 2, combined nerve trunk; 3, 3, motor root.

N.B.—No enlargement or ganglion should appear on the anterior root, only on the posterior.

diately unite with each other, and form what is called a mixed nerve. The meaning of this term we shall presently understand when we come to inquire into the functions of these parts of the nervous system.

Both the cranial and the spinal nerves are, generally speaking, mixed nerves. They are composed of a large number of nerve fibres, just as a skein of worsted is composed of a large number of individual threads. After leaving the skull and spinal column the individual fibres of which they are composed separate from one another, forming branches of the mixed nerves which pass to all parts and to all the tissues and organs of the body.

The Arrangement of the Grey and White Matter.

1. *In the Great Brain.*—The whole of the surface of the great brain is covered with a layer of grey matter, over which it spreads in a continuous sheet which is about $\frac{1}{4}$ in. thick. The object of the convolutions of the brain is to allow of an increase in the extent of this sheet of grey matter, and it follows that the more numerous and more complicated these folds and puckers are the greater will be the amount of grey matter. In addition to this extensive sheet on the surface of the great brain there are many patches of grey matter scattered deeper in the substance of the cerebrum. These secondary patches (basal ganglia, as they are called) are connected by nerve fibres with the superficial area, and are under its control. The other parts of the great brain are composed of white matter.

2. *In the Small Brain* the grey and the white matter have the same relative position to one another, as in the great brain—that is to say, the surface is composed of grey matter, while beneath this is the white matter, amongst which are found again some secondary patches of grey matter.

3. *In the Pons and Medulla* and *in the Spinal Cord* there is no grey matter on the surface, which is composed entirely of white matter. This in the spinal cord encloses the more deeply situated grey matter almost as in a tube. In the bulb and bridge, where the central canal of the cord widens out to form ventricles, the grey matter is arranged around these.

Throughout the whole nervous system the grey matter is much more abundantly supplied with blood than the white. This fact indicates that the grey matter requires more nourishment than does the white, and that the nutritive or chemical changes, whatever these may be, which are inseparable from vital activity, take place rather in the grey than in the white matter.

The Functions of the Nervous System are very numerous and complicated, but it is only necessary here to give a brief and simple description of the general principles upon which it works.

(i) The white matter, which we now know consists of nerve fibres, is the connecting link between various nerve centres or between a nerve centre and some other tissue or organ. Its function is always the same—namely, the conveyance of an impulse or message either from one nerve centre to another, or from one or more centres to some other tissue or organ, such as a muscle, or, again, from some other tissue, such as the skin or retina to a nerve centre. The nerve fibres in our body, then, wherever they may be found—that is to say, whether they form part of the white matter of the brain or of the spinal cord, or whether they form part of an ordinary spinal or cranial nerve, are like the telegraph or telephone wires that pass from one town to another all over the country, only there is this great difference, that, whereas in the case of any particular telegraph wire the message may pass in both directions along the wire, either to or fro, this is not the case with a nerve fibre, for any individual nerve fibre conveys its message always in one and the same direction, so that if a message is to be sent to any nerve centre, and an answer received back—a condition of things which constantly occurs in the everyday work of our bodies, two separate nerve fibres are necessary—along one of these fibres the message travels in the direction towards the nerve centre, and as such a message when it reaches the centre results generally in some sort of sensation, we may call such a nerve fibre a sensory nerve fibre (afferent). Along the other fibre the answer is returned, the message travelling in the direction away from the nerve centre. Now the commonest, or perhaps we should say the most readily recognisable, result of a message travelling in this direction is a muscular contraction which gives rise to some form of movement; hence we may speak of nerve fibres which convey messages away from a nerve centre as motor nerve fibres* (efferent). These two kinds of nerve fibres, afferent and efferent, are usually combined with one another in all the cranial and spinal nerves, and when this is the case the nerve is spoken of as a mixed nerve.

We have seen that each of the spinal nerves arises from the spinal cord by two roots, which almost as soon as they leave the cord unite with one another. These two roots are composed each of a particular kind of fibre, the anterior or front one being made up of all motor fibres, while the posterior or back one is made up entirely of sensory fibres.

(ii) The functions of the grey matter are of a much higher order, and are much less easy to understand than those of the white matter. It is in the cells of the grey matter that nerve impulses arise, or are received and interpreted into sensations, and the peculiar and special function of grey matter depends upon the vital activity of the nerve cells which it contains.

---

* It should be mentioned here that the motor nerves form only one of several classes of efferent nerve fibres, as will be more easily understood presently.

We have compared the function of the white matter, or nerve fibres, to that of the telegraph wires which convey messages from one part of the country to another. If we might continue our comparison, and apply it to the nerve cells of the grey matter we should say that these resemble the cells of an electric battery, which generate the electricity which is the force whereby the telegraphic message is conveyed along the wire. But the results of the activity of nerve cells are very numerous and varied. Whenever a nerve cell passes from a state of rest into one of activity, such change of condition may produce one of either of the three following results:

1. Some mental or intellectual process, thought, etc.

2. The generation of a nervous impulse which passes out from the cell through, we will say, a motor nerve, producing some kind of motion.

3. Some sort of sensation—in this case the activity of the cell being awakened by its receiving a nervous impulse arising elsewhere and conveyed to it through a sensory nerve.

During the whole period of life there is a constant flow of nervous impulses outwards from the grey matter to the various organs and tissues of the body and in the contrary direction inwards to the grey matter from the various organs and tissues of the body. The former of these impulses (those travelling away from the grey matter) pass through what are called the efferent (carrying away from) nerves. For the sake of simplicity when dealing with the functions of the white matter, only one class of these nerves—the motor nerves—was mentioned, but it may be easily understood that there are many other results of those efferent or passing away impulses besides muscular contraction. For instance, such impulses control the secretion of the innumerable glands of the body, the tears, the sweat, the urine, the gastric, and intestinal glands, etc.; others, again, control the process of assimilation and the nutrition of the tissues.

The other set of impulses (those travelling towards the grey matter) pass through what are called the afferent (carrying towards) nerves. When these impulses reach the grey matter the result of the activity of the nerve cells which they thus awaken is generally some sort of sensation such as sight, hearing, taste, smell, touch, heat, pain, etc.

Having now obtained a general idea of the uses of the two kinds of nerve tissue, we may pass on to consider the special functions of the various anatomical divisions of the nervous system.

1. *The Functions of the Great Brain.*—We have seen that the grey matter of the great brain is arranged in what we may call two systems, the outer crust or rind which we call the grey matter of the convolutions and the secondary patches which are more deeply situated and which are known as the basal ganglia. Now it is the former of these two systems which specially concerns us here, and we may leave the functions of the basal ganglia out of consideration altogether, for they are not yet very clearly understood and any attempt to explain them would lead us into realms which we have no need to explore.

In the grey matter of the cerebral convolutions resides the power of thought and that of originating motion, and here it is that the impressions which travel through the afferent nerves from the skin, from the muscles and joints, from the organs of special sense, etc., are received and interpreted into what we call sensations, awakening within us a knowledge of external events and of the condition of our own organs and tissues, the sum of these sensations being what we call consciousness. Hence we say that the functions of the great brain (cerebral convolutions) are briefly that:—

(i) *It is the Seat of the Mind*, meaning thereby consciousness, the power of thought and judgment, memory, the exercise of the will, the emotions, etc. Of these functions we have nothing more to say in this place.

(ii) *It is the seat of Motion and Sensation.*—Every voluntary movement we make depends upon and is brought about by muscular contraction, but our muscles have no power of themselves of passing from a state of rest into one of contraction; this can only be brought about by the receipt by the muscle of a nervous impulse or message. Every such nervous impulse or message arises in the grey matter of the convolutions and is conveyed therefrom to the muscles by a motor nerve-fibre. If at any time we change our condition from one of rest to one of motion, if, for example, when sitting down we suddenly conceive the idea that we will rise and walk across the room, the muscles which accomplish this movement act only in obedience to directions or commands received from the grey matter of certain portions of the convolutions. Such directions or commands or nervous impulses are the result of some sort of chemical activity in the nerve cells, of the nature of which we are quite ignorant. This chemical activity may be started by some stimulus received from outside the brain; for instance, in the example we have already taken, the movement may be induced because we feel a draught of cold air which gives rise to the thought that it would be wise to close a window or a door, and we rise to effect this purpose; or the thought or idea which results from such chemical action may arise entirely within the mind without any obvious external cause.

Now, certain portions of the grey matter of the convolutions exercise command over certain definite groups of muscles. What I mean is this, when we move our toes, the nervous impulses which result in such movement arise always from the nerve cells within a limited area of grey matter which is situated at the summit of the cerebral hemisphere, a little in front of the middle. Just outside this is a small area of cells which control the muscles which move the knee, and outside this again, those of the hip, and so on. These patches of grey matter, which, of course, cannot be distinguished from one another by any visible difference, are known as the motor areas.

Every movement we make, then, we make with our brains, the muscles being merely the mechanical means through which the brain acts, and if from any cause, as frequently happens in disease, the muscles are prevented from receiving their proper stimuli from the motor areas, they become paralysed and useless.

It is the same with sensation—we taste and feel, not with our tongues and skin, but through these with our brains. If, in the case of one who is sewing, the point of the needle should happen to enter the skin of the finger, the sewer at once becomes conscious of the fact because she feels the prick, in other words, she becomes conscious of a painful sensation. The point of the needle stimulates the end of a sensory nerve in the skin, this gives rise to a nervous impulse or message, which is conveyed along a sensory nerve-fibre into the spinal cord, and so through the white matter of the brain to the cells in the cerebral convolutions. When this impulse or message reaches the particular cell or group of cells whose business it is to receive and interpret messages from the point of the finger, and not till then, we become conscious of a painful sensation; if through disease these particular cells should be destroyed, or the nerve-fibre in any part of its course interrupted, all sensation in the finger would be lost and one might stick needles into it and feel no more pain than if one were sticking them into a pin-cushion, although the appearance of the skin might not be altered in the least degree.

The grey matter of one cerebral hemisphere controls the movements and receives the sensory impressions from the opposite side of the body. The reason of this is that the nerve-fibres in their passage through the spinal cord cross over from one side to the other, so that those which come from the nerve-cells of the left side of the brain pass to the muscles of the right side of the body, while those which come from the skin of the right side of the body convey sensory impressions to the cells of the left side of the brain.

2. *The Functions of the Cerebellum.*—This portion of the brain appears to be concerned chiefly in harmonising the various muscular movements and in balancing the body. A pigeon whose cerebellum has been removed, although still quite capable of voluntary movement, cannot effect any definite or regular purpose. Instead of flying it flutters, the movements of its wings being clumsy and irregular; there is, however, no paralysis or loss of intelligence.

3. *The Functions of the Pons and Medulla.*—The grey matter of the intermediate brain contains many nerve centres which control various more or less unconscious movements which are of vital importance. Such, for instance, are the movements of respiration, the movements of the heart and blood-vessels, the act of swallowing, etc.

4. *The Functions of the Spinal Cord.*—From what has been already said, it will be easily understood that the white matter in the spinal cord consists largely of nerve fibres on their way to and from the brain, so that it is obviously a great conducting

medium. The cells of its grey matter carry on many functions, of which we need only mention two: (1) they exercise a great influence over the nutrition of the muscles, and (2) they are the centres for

Reflex Action.—A reflex action may be defined as an involuntary or unconscious movement which is dependent for its causation upon an afferent (sensory) stimulus. It will be better understood by an example. If, for instance, a finger is suddenly pricked with a needle, the hand is instantly withdrawn, or if a light be suddenly flashed before the eyes the eyelids are involuntarily closed, or when the feeding teat is placed between a baby's lips the baby immediately commences the movements of sucking. All these actions are performed without the intervention of the will and are examples of reflex action.

For the carrying-out of every reflex action, certain definite structures or tissues are required. These are (1) a sensory surface for the receipt of the stimulus. In the above instances this consists of the skin, the retina, the mucous membrane of the lips.

(2) An afferent nerve which conveys the stimulus from the sensory surface to

(3) one or more nerve cells (a nerve centre).

(4) An efferent nerve which conveys the (reflected) impulse back from the nerve centre, to

(5) one or more muscles.

Many of the ordinary actions of our daily life are carried out reflexly. A large number of them have for their object the preservation of life or the prevention of injury, or the removing of some irritating or deleterious object. As examples of the latter may be mentioned sneezing, coughing, and vomiting.

Common Sensation.—In its waking state the brain is continually receiving a set of stimuli or sensations through the skin. Such are the sense of touch, the sense of pain, of heat and cold. These are together spoken of as common sensation.

From the muscles, also, the brain receives afferent impulses whereby we are enabled to judge of the amount of contraction which takes place in them when we move, and also of their position. This is the muscular sense, and by it we can tell without using our sense of sight, whether our limbs are flexed or extended.

The Special Senses are sight, hearing, taste, and smell, and for their reception we are provided with special organs, which in the case of sight and hearing, at least, are of an extremely complicated kind; less so in that of taste and smell. Into the structure of these organs it is not necessary for us to enter.

It is through these various senses that we become cognisant of our surroundings, and, as we shall see in a later section, the proper development of the mind depends very largely upon them.

II. *The Sympathetic Nervous System.*—This consists of a double chain of nerve swellings or ganglia, as they are called, lying in front of the bodies of the vertebræ in the neck, thorax, and abdomen. Each ganglion is connected to the one above and below it and to its neighbour by nerve fibres. Connected with this chain are networks or plexuses of nerve fibres scattered among the thoracic and abdominal contents. The sympathetic system receives fibres from and is under the governing control of the cerebro-spinal system. It is concerned chiefly in the regulation of various vital processes of which we are ordinarily more or less unconscious, and over which we are unable to exercise any voluntary influence. It supplies the involuntary muscles of the heart, arteries, stomach, intestines, etc.

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